Traditions and Transformations: Approaches to Eneolithic (Copper Age) and Bronze Age Metalworking and Society in Eastern Central Europe and the Carpathian Basin

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Table of Contents

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1
Introduction

This study was conceived of some years ago as a sequel to the metallographic examination of Early Bronze Age axes from the north alpine region of central Europe (Kienlin 2008a). The original impetus was to provide a long-term perspective on the development of methods of casting and forging by extending the data base to Eneolithic/Copper Age material. In addition, by a shift east to the Carpathian Basin an attempt was made to allow for the existence of different traditions of early metalworking and compare regional trajectories into the metal ages. The approach may be termed cognitive since metallographic data, that is the examination of a metal object's microstructure, is used to reconstruct chaînes opératoires in the production of early metal objects and to compare the knowledge Eneolithic/Copper Age and Bronze Age metalworkers had gained of the different types of copper and copper-based alloys they were working.

So in the first instance this is an archaeometallurgical study in the early phases of metallurgy in parts of central and south-eastern Europe. Metallographic data from a large series of Eneolithic/Copper Age shaft-hole axes and flat axes is first published here in detail. The findings from this examination are discussed and both groups of implements are compared in terms of variation in their production parameters. This variation is related to both the technological change that came about during the Eneolithic/Copper Age and to a shift in emphasis placed on the production of shaft-hole implements and more mundane flat axes respectively. The reader not familiar with some of the more techniqual terms used is referred to appendix I and introductions to metallography available both in English and German (e. g. Scott 1991; Schumann 1991). The conclusions drawn, however, relate to genuinely archaeological questions. At least, the author hopes that they are of wider archaeological relevance and they are framed in such terms as to arise the interest of an archaeological audience beyond the sub-discipline of archaeometallurgy. There is also new data on Bronze Age material contained in this study, but most discussions related to that period draw on previously published data as well and try to integrate both data sets into a more comprehensive picture than was previously available.

In the course of writing this study, however, dissatification grew with both a strictly scientific approach and much mainstream archaeological writing on the social and cultural implications of copper production and working. To put it plainly, the author feels as an archaeologist with a strong interest in early metallurgy and heavy leanings towards cultural anthropology, not as an archaeometallurgist. The previous study referred to above deliberately refrained from blending a cognitive approach to early metallurgy into wider debates on craft specialisation and social context. It was felt that it is precisely from such blending, from the lack of methodological rigour and the acceptance of commonplace arguments on social context into the history of early metallurgy that most interpretative problems in this field arise. Yet interpretation cannot be avoided. Metallurgy did not develop in the void and in any case many reviews of the subject tend to give the impression of inevitable technological progress and increasing social complexity to support this craft. Hence, in the present study there is more of 'opinion' and an attempt is made to counter some of the more widely held evolutionist conceptions of early metallurgy and its role in society. Lest the reader be confused by the resulting combination of long-standing interests in both archaeometallurgy and Eneolithic/Copper Age to Bronze Age society, the approach taken and the structure of this volume require some explanation.

To start with, this is not a piece of theoretical archaeology nor is there a new or coherent approach argued for such as the 1990s programmatic (or maybe rather dogmatic) calls to move the field of archaeometallurgy towards an agency-based understanding of technology and society. Rather the approach taken loosely draws on cultural anthropology in a pragmatic way and it may certainly be called contextual due to its insistence that narratives of technological progress and the emergence of elites in control of metallurgy be tested against the evidence. Early metallurgy was far from a science-based understanding of the processes involved. It was not purposive experimentation leading in this or that direction of perceived 'progress' but it was a cultural phenomenon or expression that needs to be understood in its given context. Furthermore, the practice of metallurgy took place in Eneolithic/Copper Age and Bronze Age groups widely different in terms of economy, social organisation and cultural complexity. This variation must

not be neglected and rectified into a coherent and often evolutionist picture of the rise of metal age society.

Broadly speaking this volume falls into two parts, the first one on aspects of Eneolithic/Copper Age metallurgy (chapters 2 to 5), the second one on the development of Bronze Age metallurgy and related interpretative problems (chapters 6 to 8). In each of these sections at first there is a review of the metallurgy-related evidence from the period in question (chapters 2 and 6). These chapters are not supposed to replace a number of more detailed syntheses of early metallurgy that are available. But they provide a background to subsequent discussion and they may be of use to the reader not familiar with the subject of archaeometallurgy and the development of copper production and working in detail. Emphasis is also put on the cultural setting, in which the practice of metallurgy evolved, but more importantly throughout these chapters a first attempt is made to draw attention to some shortcomings of our conventional approach to early metalworking. It is argued that we employ notions of progress and evolution to account for long-term technological change that fall short of representing a more complex ancient reality. With the benefit of hindsight we see ‘progress’ and increasingly better solutions in the production and working of copper and copper-based alloys when in fact there were alternative trajectories and change towards the ‘better’ in modern terms was far from immediately apparent. As a result our approaches often are reductionist.

In the chapters that follow the metallographic evidence from the examination of Eneolithic/Copper Age and Bronze Age axes is presented and discussed (chapters 3 and 4 and 7 respectively). Metallography is not a universal remedy to the interpretative problems in the study of early metallurgy mentioned. However, unlike a purely analytical approach that focuses on copper composition as a guide to provenance it can certainly improve our understanding of technological choices that depended on local cultural background as much as they did on the laws of nature involved in the production and working of copper. The data available cover the development of early metallurgy in the Carpathian Basin and central Europe from what is locally termed the Late Neolithic, Eneolithic or Copper Age into the Bronze Age. Throughout, of course, it should be borne in mind that only axes were examined, that is weapons or implements. The production of copper and bronze ornaments may be an altogether different matter that requires future attention and comparable metallographic work. Some aspects of the development of metallurgical knowledge touched upon in these chapters are specific to the time and area under consideration. Technology has got style and the differences observed in the approach to forging of older and younger Eneolithic/Copper Age shaft-hole axes and flat axes respectively provide a very good example for this statement (chapters 3 and 4). Another one is the working of different types of Early Bronze Age (fahlore) copper discussed in chapter 7 and the influence this tradition had on the adoption of tin bronze. These are case studies but it is proposed that some of the points raised may be of wider relevance to the study of early metallurgy – in particular the need for a long-term perspective on the development of metallurgical knowledge that allows for contingency in technological choices and a context-specific approach to early metalworking beyond our modern science-based understanding of technological progress.

For this reason, the final chapters of both the Eneolithic/Copper Age and the Bronze Age sections seek to broaden the perspective beyond mere technology. To start with, in chapter 5 as well as in chapter 8 aspects of the function and the meaning of the axes are discussed. But the overall approach to ‘context’ taken is different in both cases. Since there is little direct evidence for the organisation of early metalworking such as workshops, chapter 5 turns to Eneolithic/Copper Age society as a whole in an attempt to bring some light to the social and political organisation of the communities in which metallurgy was practised during this period. From a theoretical point of view it is asked why we are so ready to accept a link between elites and metallurgy. An alternative model for the kinship-based organisation of metalworking and the spread of metallurgical knowledge in Eneolithic/Copper Age society is suggested. It is argued that the emphasis on social hierarchisation in the wake of metallurgy is largely derived from just one site, the famous cemetery of Varna. Different regional trajectories tend to be neglected and an attempt is made to restore variability in our perception of the social context of early metalworking by confronting Varna with the quite different evidence provided by Eneolithic/Copper Age ‘tribes’ of the Carpathian Basin.

The same approach is viable for the Bronze Age since the ‘rise of Bronze Age society’ in terms of social hierarchisation and craft specialisation is often assumed rather than demonstrated. Here as well few exceptionally rich ‘princely’ graves receive undue attention while in fact there is little evidence for the existence of stable elite positions in most parts of Bronze Age central and south-eastern Europe. Instead of duplicating this discussion, however, chapter 8 is a case study that focuses on the organisation of Bronze Age mining in the Alps and the distribution of alpine copper. This bears direct reference to the previous chapter 7 because in the current model of alpine mining and metal distribution Early Bronze Age Salez type axes are interpreted as ‘axe ingots’ and directional trade in such artefacts is assumed. The metallographic evidence is used to contradict this position. On a more general level, however, chapter 8 seeks to deconstruct modernist notions in the interpretation of Bronze Age mining, metalworking and the distribution of copper objects. Instead, a kinship-based approach to the seasonal exploitation of alpine ore deposits, at least during the Early Bronze Age, is argued for that also accounts for small-scale patterning in the analytical data that is available.

2
The Earliest Metalworking in South-Eastern and Central Europe: A Review of the Evidence

Research in the early history of metallurgy in south-eastern and central Europe reaches back almost to the beginnings of archaeology as an academic discipline, and it soon became entangled in the wider methodological and intellectual development of prehistoric archaeology. As early as 1836 Ch. J. Thomsen used the succession of stone, bronze and iron implements to establish his chronological framework (Eggert 2001, 33–35; Hansen 2001a) underlying our tripartite system of European prehistory, which increasingly came to draw upon notions of technological progress and its supposed effects on the wider domains of culture and society (Trigger 1989, 73–86). Somewhat later it was realised that at least in some parts of Europe, copper was in fact the first metal widely used not bronze (Lichardus 1991b). This finding added complexity on the terminological side for early metalworking communities, which may now be designated as (Late) Neolithic, Eneolithic, Chalcolithic, Copper Age or (Early) Bronze Age depending on regional context and archaeological tradition. Some of the earliest analyses of prehistoric copper and bronze objects were carried out with such chronological questions in mind, for example the use of copper before bronze (e. g. Montelius 1900; 1903). Ever since the application of scientific methods, the emerging sub-discipline of archaeometallurgy, has played an important part in the study of early metalworking in prehistoric Europe. Large-scale projects were carried out with thousands of chemical analyses, typically focusing on composition as a guide to provenance (e. g. Junghans/Sangmeister/Schröder 1968). Attention is less often paid to the knowledge gained by prehistoric metalworkers of the properties of the different types of copper and copper alloys they were working and to the development of methods of casting and forging (e. g. Northover 1996). Summing up much of this scientific work are a number of important syntheses, which are also drawn upon in this section (e. g. Tylecote 1987; Pernicka 1990; Ottaway 1994; Craddock 1995; Krause 2003; Craddock/Lang 2003; La Niece/Hook/Craddock 2007; Ottaway/Roberts 2008).

Science, however, is not dissimilar to archaeology in that analyses (data) are in need of interpretation. The early work of H. Otto and W. Witter (1952) or R. Pittioni (1957) and E. Preuschen (1967), who thought they had proven Bronze Age copper production in the German Ore Mountains and the eastern Alps respectively, provides an example that world view must not be neglected in archaeometallurgy either. This tends to be concealed by the application of ever more sophisticated analytical methods, which is also the reason why specialist studies focusing on technological aspects tend to dominate the field, to the neglect of an integration of this 'functional' perspective with wider culture-historical concerns (Thornton 2009). The field of craft specialisation and social complexity is one such area that might profit from a true integration of a science-based reconstruction of technological processes and choices with an anthropologically informed discussion of its social and ideological context. Typically, however, this still takes the form of evolutionist grand narratives linking perceived technological progress to the emergence of hierarchical society (e. g. Strahm 1994). This notion goes back, of course, to V. G. Childe (e. g. 1944; 1951), who in his influental work placed the emergence of metallurgy in the urban centres of the Near East. From there Childe claimed the knowledge of copper and bronze spread to Europe, where – in a distinctly Childean turn – it was thought to have taken on a new quality: the specific freedom and creativity of itinerant Bronze Age craftsmen leading right up to modern western civilisation (Rowlands 1994). When C. Renfrew (1969) argued for an autonomous invention of metallurgy clearly such a vision of European creativity was no longer employed, and he used radiocarbon dates to defy diffusionist claims. But with the cemetery of Varna providing the social background to Eneolithic/Copper Age metallurgy (Renfrew 1978; 1986), he clearly remained in a Childean tradition of linking metalwork to the emergence of socio-political elites. Renfrew himself was subsequently criticised on the basis of new data (e. g. Pernicka 1990, 32–40). Today many would hold the autonomous invention of metallurgy an open question, relying on evidence that might still come to light from the contemporaneous Aegean and Greece, or flatly opt for single invention in the east (e. g. Parzinger 1993, 347; Ottaway/Roberts 2008, 197; Roberts/Thornton/Pigott 2009).

More importantly, however, this debate brings us back to early metallurgy, archaeometallurgy and world view. At least in some local research the oldest traces of metalworking in south-eastern Europe and the autonomous invention of metallurgy were a matter of national pride (e. g. Todorova

1978, 1; cf. Evans/Rasson 1984). New data, for example an earliest radiocarbon dated metal workshop in Bulgaria or Turkey, might encourage or defy such claims, but the same is not true in a straightforward sense for Renfrew's approach. Metallurgy may eventually be proven to be a Near Eastern or south-western Asian invention, but his call to move archaeology beyond diffusionism and towards an understanding of innovation and culture change in terms of local and regional dynamics clearly stands. Questions to be asked may concern the existence of elites and their role in the spread of metallurgy, symbolic aspects of metalworking and the potential of (prestigious) copper and bronze objects to cause culture change. Not everyone would share Renfrew's view of causality, and there is clear evidence of the practice of metallurgy in groups with little evidence of socio-political hierarchisation (e. g. Copper Age Tiszapolgár in the Carpathian Basin; Whittle 1996, 72–76; Bailey 2000, 168–169, 194–195; Lichter 2001, 289–291). In south-eastern and central Europe early metalworking from the 5th to the 2nd millennium BC took place in groups widely differing in cultural and organisational complexity. This prompts questions as to the different strategies of incorporating copper and bronze into existing cultural schemes and vice versa the impact of metalworking and metal objects on the societies in question. Beyond the call for additional (archaeological and scientific) data this clearly involves a discussion of 'theoretical' aspects, i. e. the role of technology in society, the social context of early metalworking, its meaning and symbolic implications.

In its early stages 'metallurgy' – i. e. not yet extractive metallurgy proper (see below) – involved the use of native copper and copper minerals as ornaments and pigments before smelting and casting were introduced. In central and northern Europe in particular there is evidence of copper artefacts imported from neighbouring areas during this phase. A number of recent syntheses try to integrate the evidence at hand into a coherent culture-historical picture, which typically involves the spread of metallurgy from south-eastern to central and northern Europe (e. g. Parzinger 1993; Klassen 2000; Müller 2001; Krause 2003). In fact, it is obvious that Late Neolithic or Eneolithic/Copper Age metallurgy in south-eastern Europe predates and was more advanced than contemporaneous Neolithic metallurgy in central Europe. But concepts of 'spread', 'influence', 'diffusion' or 'drift' do not significantly add to our knowledge of early metallurgy in the respective areas. In both regions evidence is often ambiguous as to the earliest stages of proper metallurgy, i. e. copper production by smelting, the casting and working of copper thus produced. New finds have the potential to significantly alter the overall picture.

Therefore, in this section no attempt is made to compose a coherent picture of the spread of metallurgy through south-eastern to central and northern Europe. Instead a review is provided of the earliest evidence of copper artefacts in their respective cultural setting, and the early evidence of mining for copper, smelting and the succession of different types of copper and copper alloys are discussed. Attention is drawn to interpretative problems both with the notion of technological 'progress' and commonly held perceptions of the societal context of early metallurgy. It will become clear that previously clear-cut technological stages tend to become blurred by new discoveries. We cannot rely on evolutionist assumptions and/or geological conditions as a guide to the development and 'progress' of metallurgy any more. The introduction of metallurgy and its subsequent development was the result of technological choices drawing upon and embedded in the respective groups' cultural and social texture. These choices were taken by actors firmly integrated in networks of communication and decision-making. They were neither determined in their action by the laws of chemistry or physics alone nor by any 'political' authority manipulating the production and circulation of 'prestigious' copper objects. This latter aspect will be explored in greater detail below, and a kinship-based model for the spread of metallurgical knowledge and the organisation of Eneolithic/Copper Age metallurgy is advocated (see chapter 5.4).

2.1 Copper and the 'Copper Age'

Concepts such as Copper Age or Bronze Age not only carry chronological implications; neither are they dependent just on the actual remains of the past societies we are studying. They often entail assumptions on the socio-cultural implications of metallurgy, which tend to go unnoticed, and heavily depend upon the academic tradition we are working in. Prior to any review of the earliest evidence of metallurgy, it is important to turn to the different approaches to periodisation employed in the area under consideration and provide an outline of the culture groups of the period in question.

Generally speaking 'Copper Age' (a term widely used e. g. in Hungary) and related terms like 'Eneolithic' (preferentially used e. g. in the former Yugoslavia) or 'Chalcolithic' are more widely used in the Carpathian Basin and on the Balkans than they are in central Europe. The obvious reason is the large number of often fairly massive copper artefacts known from south-eastern Europe. 'Copper Age' in this tradition denotes a technological stage – not necessarily coeval throughout south-eastern Europe – to be added to the tripartite system of the Stone, Bronze and Iron Ages (Lichardus 1991b, 14–17). A structural definition of the 'Copper Age' or 'Eneolithic', on the other hand, seeks to correlate technological change to perceived progress in wider economic and cultural domains (e. g. Lichardus 1991c). Problems with this approach arise because changes in economy, society and ideology – if any – are subject to debate, and in the vast area from the Black Sea to central Europe may not occur at the same time and may take different forms (Whittle 1996, 72–121; Bailey 2000, 153–239). Both strategies, technological and structural, for defining the 'Copper Age' are not easily combined since a causal relation of metal and society is hard to demonstrate.

The famous Vinča sequence – named after the eponymous tell site of Vinča-Belo Brdo in Serbia – is widely used to

Year BC (Calibrated)	Serbia	Transdanubia	Great Hungarian Plain			Transylvania	Bulgaria	Period
			Middle and Lower Tisza	Upper Tisza	Eastern Plain			
3500	Bubanj-Hum	Balaton-Lasinja	B Bodrogkeresztúr A	B Bodrogkeresztúr A	B Bodrogkeresztúr A	Pécska Bodrogkeresztúr A	?	**Middle Copper Age**
4000	Vinča D2	Lengyel III	B Tiszapolgár A	B Tiszapolgár A	B Tiszapolgár A	B Tiszapolgár A	Karanovo VI (Gumelniţa)	**Early Copper Age**
4500	Vinča D2	Lengyel III	Proto-Tiszapolgár	Proto-Tiszapolgár	Proto-Tiszapolgár	Proto-Tiszapolgár Petreşti, Erősd	Karanovo VI	**Final Neolithic**
5000	Vinča D1 Vinča C	Lengyel II Lengyel I Sopot-Bicske II	Tisza III Tisza II Tisza I/II	Csőszhalom (Oborin) Tisza I/II	Herpály III Herpály I - II Tisza I/II	Petreşti Lumea Noua	Karanovo V (Marica)	**Late Neolithic**
	Vinča B2 Vinča B1 Vinča A	Sopot-Bicske Zseliz-Notenkopf DVK	Tisza I Szakálhát AVK Körös IV	Szakálhát Bükk - Szilmeg AVK	Esztár AVK	Precucuteni I-II Criş IV	Karanovo IV Karanovo III	**Middle Neolithic**
5500	Starčevo III -IV Starčevo II Starčevo I	Starčevo III Starčevo II Starčevo I?	Körös III Körös II Körös I	Körös-Szatmár	Körös-Szatmár	Criş III Criş II Criş I	Karanovo II Karanovo I	**Early Neolithic**
6000								

Fig. 2.1: Chronology of the Neolithic and Early to Middle Eneolithic/Copper Age of the Carpathian Basin and south-eastern Europe (after Parkinson 2006, 57 fig. 4.4).

correlate culture groups of the Balkans and the Carpathian Basin and provides an excellent example of such problems (see Schier 1997; Link 2006, 15–28). In its early stages the Vinča culture clearly is Neolithic (Vinča-Tordos/Turdaş after Garašanin 1951; 1973; 1993; 1995; 1997; roughly Vinča A and early B after Milojčić 1949, 70–75). But does it qualify as Eneolithic during its younger phases (Vinča-Gradac and -Pločnik after Garašanin 1993; 1995; 1997; roughly Vinča B late, C and D after Milojčić 1949) because of the beginning use of copper and copper mining (e. g. Jovanović 1971; 1982; 1996; Garašanin 1979; 1995; 1997)? Or should we refer to this period as Late Neolithic (e. g. Tasić 1994, 20–21) because it is only with the end of Vinča (-Pločnik/Vinča C2/D) that there is evidence of profound culture change, and (Late) Neolithic tell settlement comes to an end (Link 2006, 15; Parkinson 2006, 40–63)?

Following the latter definition (fig. 2.1) the Late Neolithic of the northern-central Balkans and the Carpathian Basin comprises late Vinča (-Pločnik/Vinča C–D) in northern Serbia, in the Vojvodina and the Banat regions as well as the Tisza culture north of the Danube extending along the floodplain of the eponymous river Tisza (fig. 2.2A), with the somewhat later but closely related Herpály and Csőszhalom groups (Tisza-Herpály-Csőszhalom complex). In the western part of the Carpathian Basin the Sopot (III/IV) culture along the rivers Drava and Sava in Slavonia as well as Lengyel (II/III) in Transdanubia belong to this period. Defined and further subdivided mainly by their distinctive pottery styles these groups (with the exception of Lengyel which has stronger affinities with central Europe; e. g. Kozłowski/Raczky 2007) nonetheless share some distinctive traits. With some regional variation, these in particular are settlement burial and a complex settlement system, with firmly integrated communities drawing their cultural identity from elaborate ritual and permanent focal tell sites in the landscape (Meier-Arendt 1990; Parzinger 1993, 260–263, horizon 6 and 7; Whittle 1996, 101–112; Bailey 2000, 162–169; Gogâltan 2003; Parkinson 2006, 43–51; Link 2006, 18–41).

In contrast, the subsequent Early Copper Age (Hungarian terminology) Tiszapolgár culture (figs. 2.1 and 2.2B) is noticeable for its homogeneous pottery, which is distributed over large parts of the Great Hungarian Plain. Judging from the pottery evidence there was continuity in population between the Late Neolithic and the Early Copper Age. But the earlier tell sites were abandoned, and Tiszapolgár is characterised by a dispersal of settlement and the appearance of extramural cemeteries (Bognár-Kutzián 1972; Parzinger 1993, 263–265, horizon 8; Lichter 2001, 267–293; Parkinson 2006, 51–55; Link 2006, 33–35). This pattern continues into the Middle Copper Age (Hungarian terminology), the Bodrogkeresztúr culture, with some changes to pottery form and decoration as well as an extension of this culture's area to the west, with new sites occurring in the interfluvial zone between the Tisza and the Danube rivers (figs. 2.1 and 2.2C; Patay 1974; Parzinger 1993, 265–267, horizon 9; Lichter 2001, 311–353; Parkinson 2006, 55–63). In Transdanubia it is

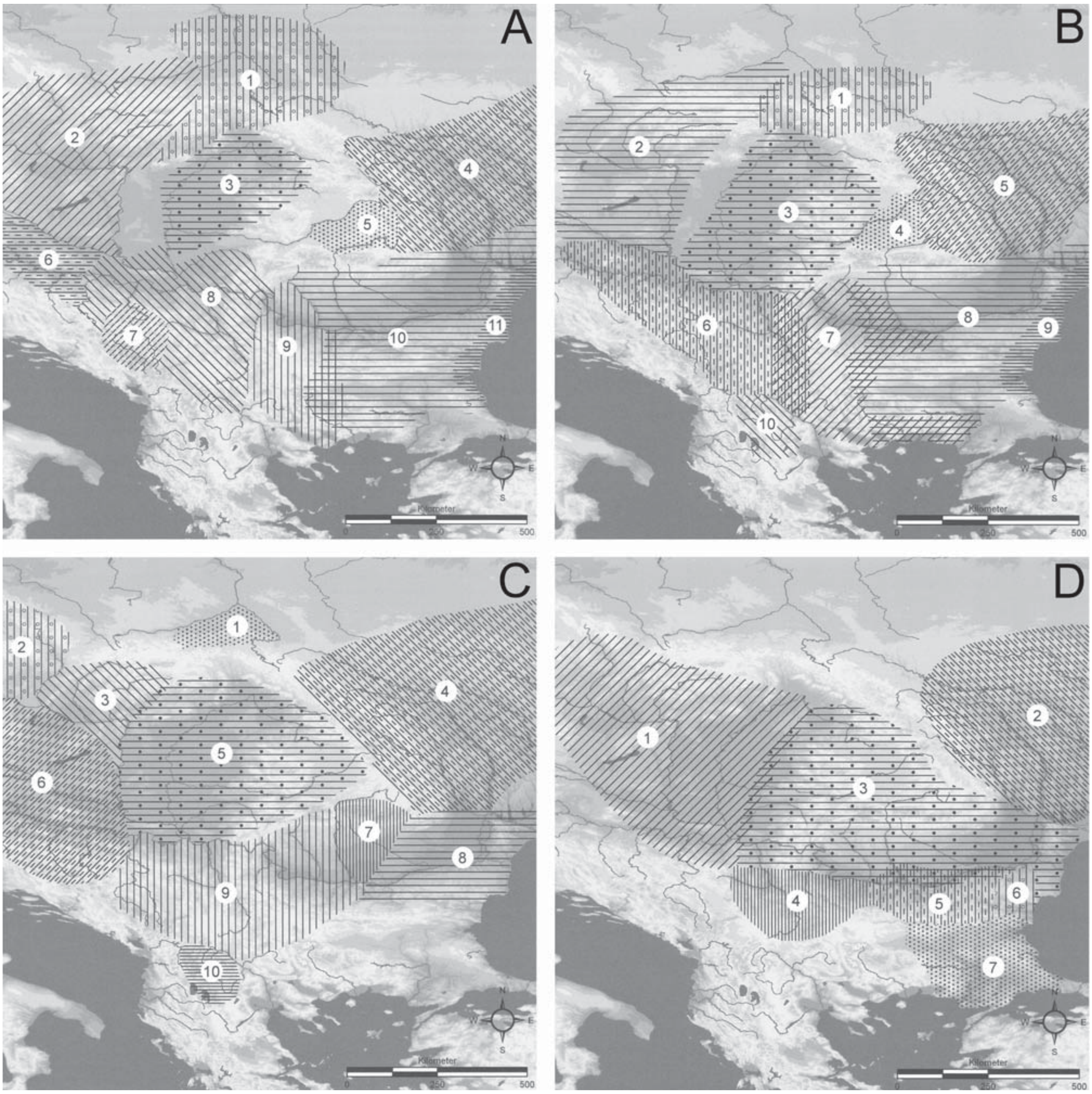


Fig. 2.2: Distribution of Late Neolithic and Eneolithic/Copper Age cultures in the Carpathian Basin and south-eastern Europe (after Schreiner 2007, 71 fig. 4.1, 75 fig. 4.2, 76 fig. 4.3, 83 fig. 4.7). A: Late Neolithic (1. Stichbandkeramik; 2. Lengyel 2; 3. Tisza-Herpály-Csőszhalom; 4. Cucuteni-Tripolje A; 5. Petreşti; 6. Sopot 3; 7. Butmir; 8. Vinča D; 9. Krivodol-Salcuţa 1; 10. Kodžadermen-Gumelniţa-Karanovo VI; 11. Varna); B: Early Eneolithic/Copper Age (1. Złota-Lublin; 2. Lengyel 3; 3. Tiszapolgár; 4. Petreşti; 5. Cucuteni-Tripolje AB; 6. Vinča D/Sopot; 7. Krivodol-Salcuţa-Bubanj Hum; 8. Kodžadermen-Gumelniţa-Karanovo VI; 9. Varna; 10. Šuplevec-Bakarno Gumno); C: Middle Eneolithic/Copper Age (1. Złotniki; 2. Jordanów; 3. Ludanice; 4. Cucuteni-Tripolje B; 5. Bodrogkeresztúr; 6. Balaton-Lasinja 1; 7. Brateşti; 8. Černavodă 1; 9. Salcuţa 3; 10. Šuplevec-Bakarno Gumno); D Late Eneolithic/Copper Age (1. Boleráz; 2. Horodiştea-Folteşti 2; 3. Černavodă III/Coţofeni; 4. Bubanj Hum; 5. Orlea-Sadovec; 6. Ezerovo; 7. Ezero).

only at this stage, with some delay compared to Tiszapolgár, that the late Lengyel (IIIb) evolves into the Eneolithic/Copper Age Balaton-Lasinja culture as well as Ludanice north of the Danube. On the northern and central Balkans, late Vinča (-Pločnik/Vinča D) is replaced under influences such as from Eneolithic Bubanj-Hum Ia/Sălcuţa II, a process that requires regional differentiation (Kalicz 1995; Link 2006, 27–28, 37–41; Schreiner 2007, 70–78). The Bodrogkeresztúr horizon is followed up by Hunyadi-halom and the *Furchenstichkeramik* groups further west before with (early Baden-) Boleráz and the Baden culture we come to the end of the Eneolithic/Copper Age sequence (Patay 1984, 7 fig. 1; Kalicz 1991; Parzinger 1993, 267–269, horizon 10 and 11; Roman/Diamandi 2001; Schreiner 2007, 78–85).

The Boleráz and Baden, Cernavodă III and Coţofeni horizons respectively represent significant cultural change

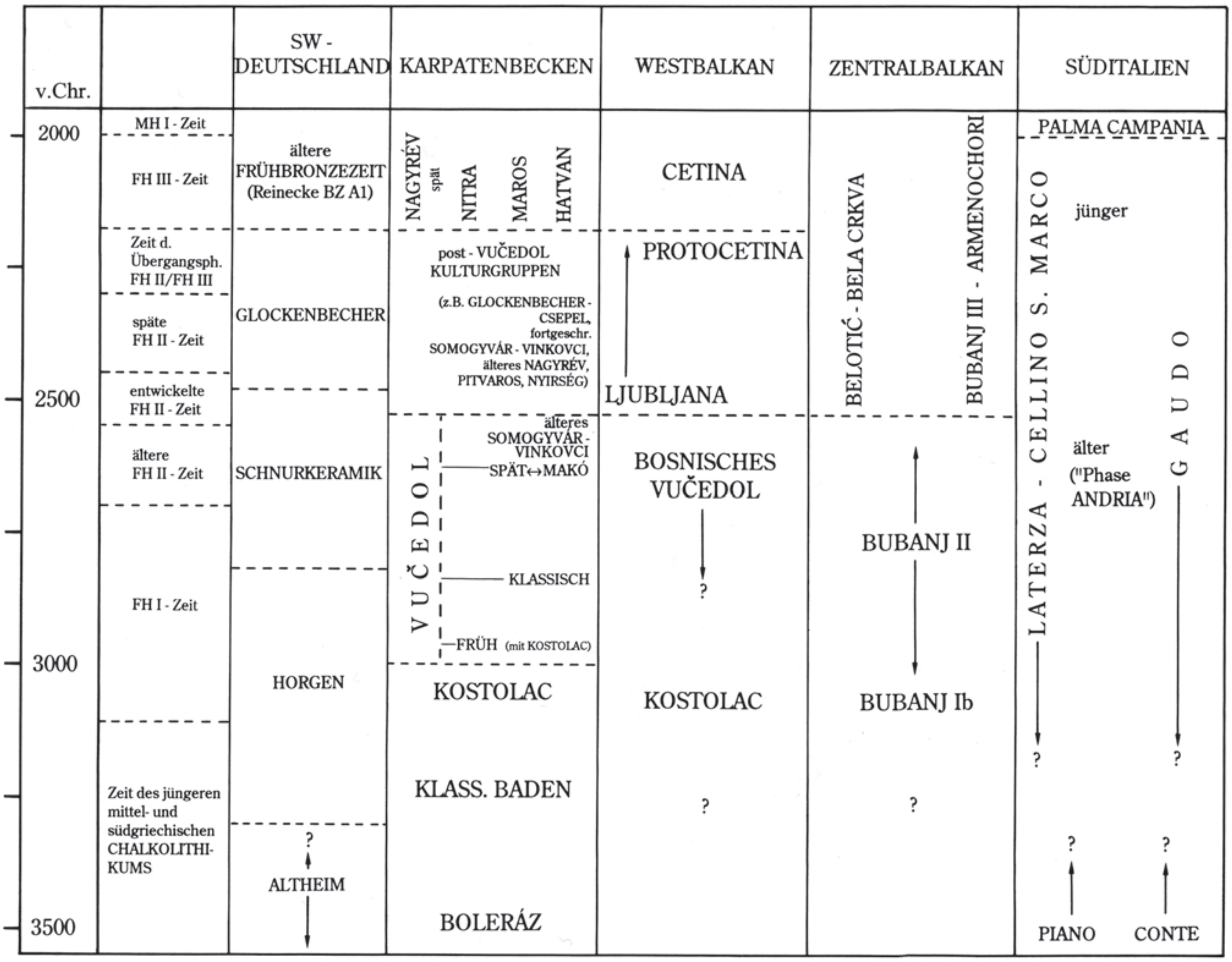


Fig. 2.3: Chronology of the Late and Final Eneolithic/Copper Age of the Carpathian Basin and surrounding areas (after Maran 1998, tab. 82).

in wide areas of the western Carpathian Basin and adjacent areas in that the earlier copper industry came to end (figs. 2.2D and 2.3). No more heavy copper implements were produced and in fact very little is known about the metallurgy of this period (Parzinger 1993, 348–351; Whittle 1996, 122–143; Bailey 2000, 240–262; Schreiner 2007, 82–85). Finally, further east towards the Black Sea in Bulgaria at about the time of Tiszapolgár there is the so-called Kodžadermen-Gumelniţa-Karanovo VI complex (KGK VI), locally classified as Late Eneolithic/Copper Age (figs. 2.1 and 2.2), which is known from cemeteries and the Eneolithic/Copper Age tell sites typical of this area. The famous Varna cemetery belongs to the end of this period (phase III of the so-called Varna culture; but see the absolute dates below). The preceding Early and Middle Eneolithic/Copper Age development of Bulgaria comprises cultures such as Marica and Poljanica, predating the Eneolithic/Copper Age development of the Carpathian Basin and the northern Balkans already outlined (Todorova 1978; 1982; 1991; 1995; Parzinger 1993, 260–267; Whittle 1996, 79–96; Pernicka et al. 1997, 43–57; Bailey 2000, 156–161; Lichter 2001, 29–32, 75–132).

In absolute terms the Eneolithic/Copper Age in Bulgaria is thought to have started early in the 5th millennium BC and reached its climax with the KGK VI complex during the second half of the 5th millennium BC. Recently, it was shown that the Varna cemetery – conventionally dated to the Varna III group i. e. the end of KGK VI – actually dates to c. 4560–4450 cal BC, that is earlier than expected and coeval in absolute terms with neighbouring Middle Eneolithic/Copper Age sites (Chapman et al. 2006; Higham et al. 2007). On the northern Balkans the Neolithic Vinča sequence starts c. 5400/5300 cal BC and Late Neolithic Vinča (-Pločnik/Vinča C-D) is dated to c. 5000 to 4500/4400 cal BC (Link 2006, 41); more recently a somewhat earlier end about 4650/4600 cal BC has been suggested (Borić 2009, 234–237). The Late Neolithic Tisza culture of the Carpathian Basin starts about 5200/5100 cal BC and comes to an end in its main area around 4700/4600 cal BC. It is followed by the intermediate proto-Tiszapolgár phase and the Early Copper Age Tiszapolgár culture proper dated to about 4400 to 3800 cal BC latest. The Middle Copper Age Bodrogkeresztúr culture has overlaping radiocarbon dates c. 4000 to 3700 cal BC. After a transitional period (Hunyadi-halom etc.) it is replaced about 3700/3600 cal BC by (early Baden-) Boleráz, with the Baden sequence coming to an end about 3000/2800 cal BC with Baden-Kostolac.

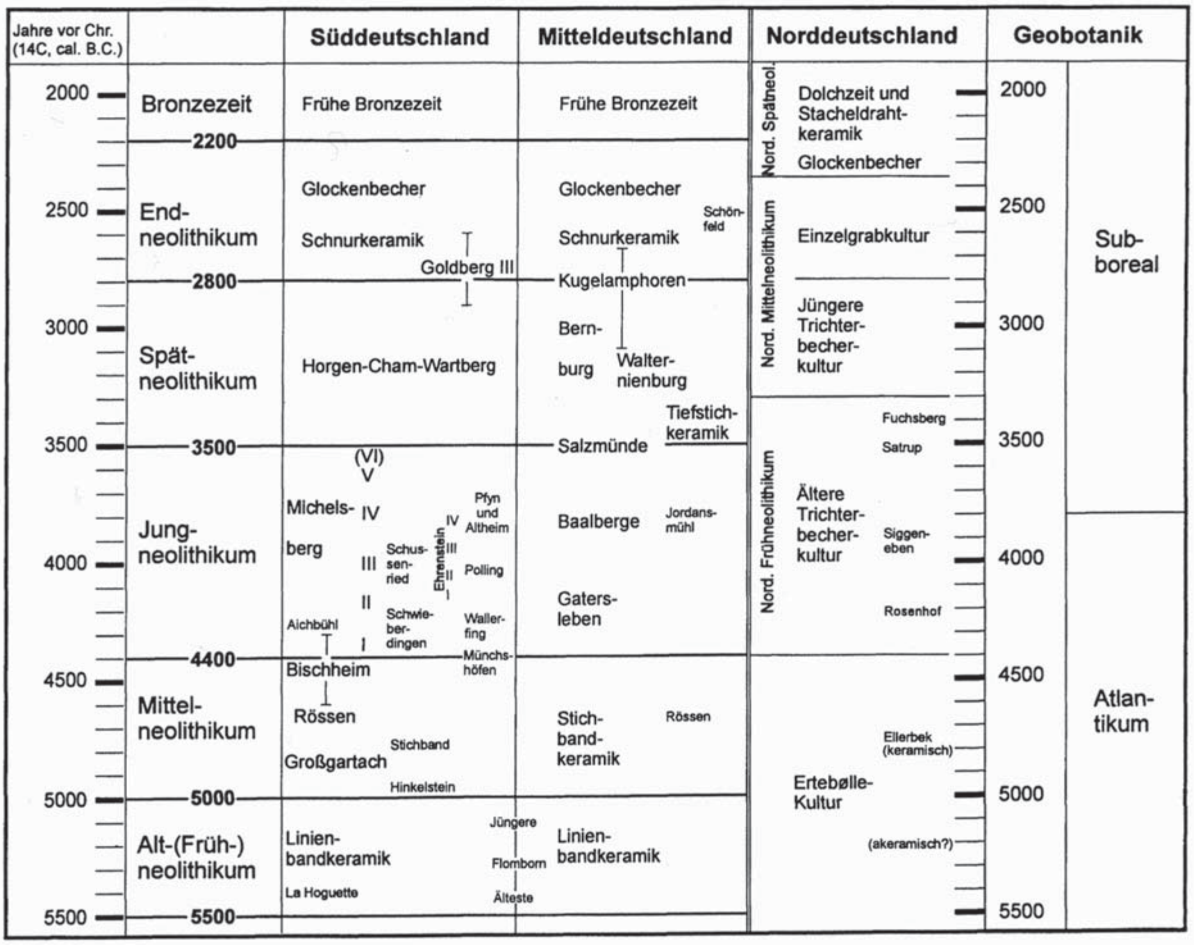


Fig. 2.4: Chronology of the central European Neolithic (after Lüning 2000, 7 fig. 2).

The Vučedol sequence succeeding (late Baden-) Kostolac is dated to about 3000 cal BC to 2500 cal BC when Early Bronze Age groups – Hungarian terminology – such as Makó make their appearance (figs. 2.1 and 2.3; Forenbaher 1993; Raczky 1995; Hertelendi et al. 1995; Maran 1998, 347–351, 354, tab. 82; Nikolova 1999, 7–15; Stadler et al. 2001; Link 2006, 41; Parkinson 2006, 57–63; Borić 2009, 234–238).

In central Europe during the 5th and 4th millennium, massive copper implements so widely distributed throughout south-eastern Europe (e. g. in Tiszapolgár and Bodrogkeresztúr contexts; Novotná 1970; Vulpe 1975; Todorova 1981; Patay 1984; Žeravica 1993) or rich grave furnishings with weapons and ornaments of copper and gold (e. g. Varna; Ivanov/Avramova 2000) are unknown, except for occasional import finds. The earliest evidence of metallurgy is small-scale (see below), for example in the Pfyn, Altheim and Mondsee groups which make their appearance around 3800 cal BC, initially synchronised with Hunyadi-halom and proto-Boleráz etc. These continue their development after c. 3600 cal BC parallel to (early Baden-) Boleráz well into the second half of the 4th millennium (Matuschik 1996, 10–11; 1997, 98–99; Maran 1998, 348–349). Neolithic traditions persist in society and economy, and the term ‘Copper Age’ (as well as Eneolithic or Chalcolithic) is not in general use in this part of Europe. This is despite attempts to redefine the central and western European Late Neolithic as ‘Copper Age’ and link the cultures in question to contemporaneous south-eastern Europe, largely on the basis of supposedly widespread changes in society and economy (Lichardus 1991c, 770–788; Klassen 2000, 17–22, 295–301; 2004, 325–339). This approach did not win general acceptance because it both tends to neglect the apparent regional differences during the period in question and because of its underlying assumptions on Eneolithic/Copper Age society. Instead the period in question is referred to as (Late) Neolithic (fig. 2.4) with the most widely used scheme by J. Lüning (1996) differentiating between *Jungneolithikum* (c. 4400–3500 cal BC) comprising the Michelsberg culture and more local groups such as Pfyn, Altheim and Mondsee and *Spätneolithikum* (c. 3500–2800 cal BC) with groups such as Horgen, Cham and Wartberg – followed by the final Neolithic Beaker cultures (*Endneolithikum*, c. 2800–2200 cal BC).

2.2 Pigments and Beads to Axes: The Evolution of Symbols?

The symbolic use of native copper and attractively coloured copper ores (copper carbonate minerals: azurite and malachite) as ornaments has recently been declared a feature of the original Neolithic package (Thornton 2001; Borić 2009, 237–238). In Anatolia and the Levant there is

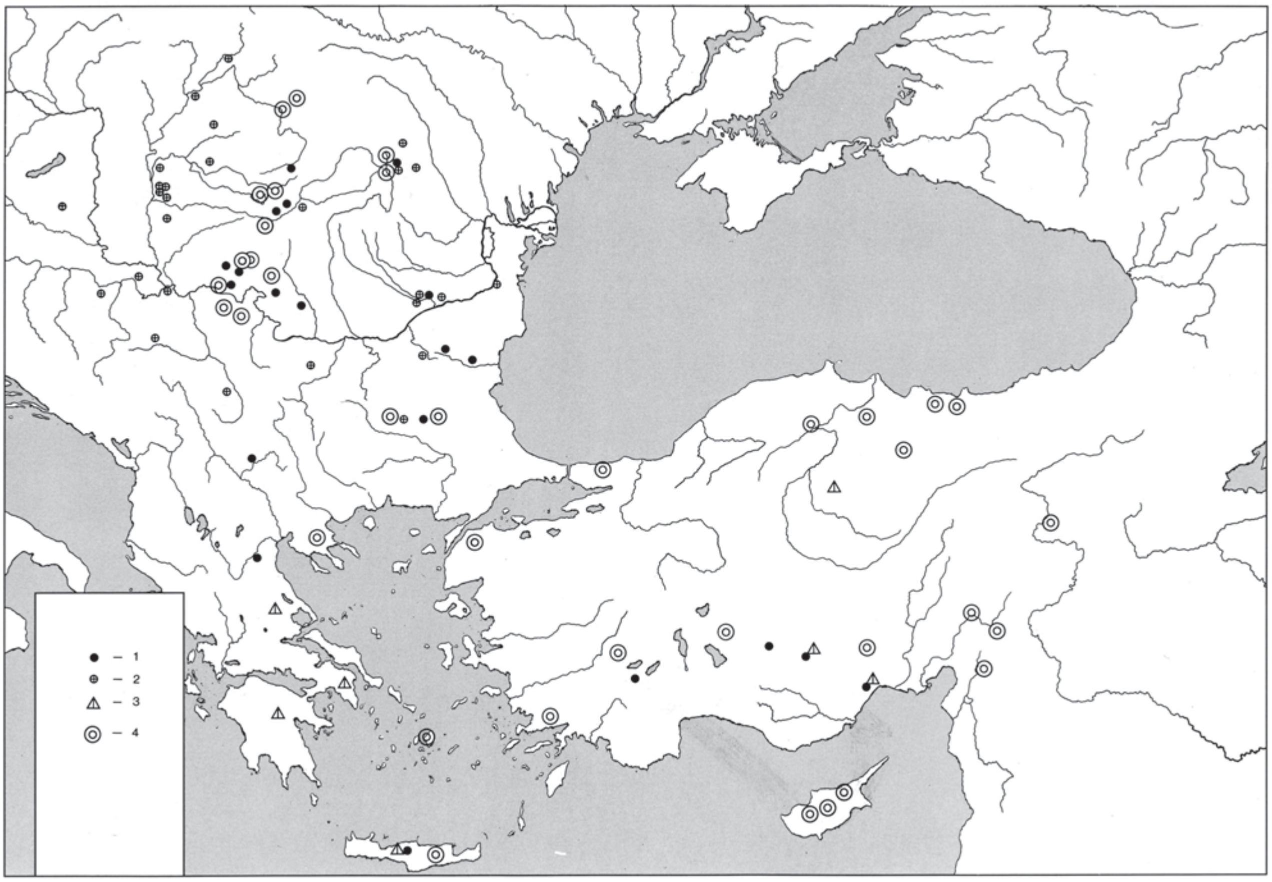


Fig. 2.5: Distribution of Neolithic copper artefacts in Anatolia and south-eastern Europe (after Parzinger 1993, tab. 227; 1: small copper objects of horizons 1–5, 2: small copper objects of horizons 6–7, 3: heavy copper implements of horizons 6–7, 4: copper ore deposits).

evidence for the use of copper minerals as pigments and native copper for small artefacts such as beads, rings and awls from the mid-9th millennium BC pre-pottery Neolithic onwards (e. g. Çayönü, Hallan Çemi, Aşıklı Höyük, Çatal Höyük; Ottaway/Roberts 2008, 195; Roberts/Thornton/Pigott 2009, 1013). Work involved grinding copper minerals (pigments/ornaments), hammering to shape and the application of heat (annealing) to restore deformability of native copper once the material became brittle (Pernicka 1990, 28–31; Schoop 1995; Özdoğan/Özdoğan 1999; Maddin/Muhly/Stech 1999; Yalçin/Pernicka 1999; Yalçin 2000; Esin 2007). Heating to modify the mechanical properties of matter and also its colour can be traced back to the working of flint and wood. Once pottery was introduced it would have been a widespread notion in Neolithic society. The concept of 'pyrotechnology' refers to this technological background (e. g. Wertime 1979; cf. Ottaway 1994, 7–14), and a comparison of the different *chaînes opératoires* involved may improve our understanding of the early use of copper (e. g. Ottaway 2001; Ottaway/Roberts 2008; Roberts 2008). There are debates over whether the working of native copper and copper minerals at this stage involved new features and strategies not otherwise applied in the contemporaneous production of tools and ornaments from other materials. Generally speaking, the earliest interest in native copper and copper minerals falls into the wider field of Neolithic communities' involvement with their natural surroundings, and their attempts at the manipulation of matter (Whittle 1996, 113–120; Bailey 2000, 209–229). It must not be seen as purposive experimentation in a modern sense, leading up to the 'science' of metallurgy, but may rather refer to symbolic concerns expressed and negotiated through material culture. In any case, this development predates proper metallurgy, which apart from working native copper and copper minerals should include mining for the deliberate production of copper ore, smelting and casting. These are somewhat later developments.

2.2.1 The Earliest Copper Artefacts in South-Eastern Europe

In south-eastern Europe and on the Balkans the earliest artefacts made of copper and copper minerals include beads, fish-hooks and awls. They are representative of a pre-metallurgy phase and are known from Early to Middle Neolithic contexts such as the Starčevo/Criş settlements of Iernunţ and Balomir in Transylvania, the Starčevo site of Obre I in Bosnia, Early Neolithic levels of Ovcharova I in Bulgaria, Middle Neolithic (phase IIIa and IIIb) Lepenski Vir in the Danube Gorges or from the early layers of some Vinča culture sites (fig. 2.5; Srejović 1973, 164–176; Glumac 1988; Glumac/Tringham 1990, 559–560; Pernicka 1990, 31–32; Parzinger 1993, 344–345; Whittle 1996, 117–118; Bailey 2000, 209–210; Thornton 2001, 24–25

tab. 2; Borić 2009, 191–192). Reflecting the spread of the Neolithic way of life they are younger than the earliest corresponding evidence from Anatolia and date from the mid-6th millennium BC onwards.

A significant increase in the number of such finds occurred during the early 5th millennium BC in the Late Neolithic (Eneolithic) Vinča culture on the northern-central Balkans (Vinča-Gradac and -Pločnik phases) and neighbouring Late Neolithic groups of the Carpathian Basin such as Sopot, Lengyel, Tisza and Herpály. Apart from beads and awls already known from previous periods and the abundant finds of copper minerals from the Vinča settlement of Belovode, this phase saw an expansion of the copper artefact types in use. Though still mostly ornaments there were more massive bracelets/armbands and an occasional chisel, e. g. from the Vinča tell sites of Pločnik, Divostin and Gomolava, from Marica, Präcucuteni and Petreşti sites further east and Tisza/Herpály contexts such as Berettyóujfalu-Herpály (Bognár-Kutzián 1976; Chapman 1981, 125–130; Glumac/Tringham 1990; Parzinger 1993, 260–263, 345, horizon 6 and 7; Zalai-Gaál 1996; Bailey 2000, 210–213; Thornton 2001, 24–25 tab. 2). There is an ongoing discussion over the earliest occurrence of heavy copper implements such as chisels and axes relating, for example, to the 'hoards' or rather settlement finds from Pločnik. Their precise position in the sequence of this site is unclear. Apparently they are late within the Vinča culture development but not intrusive from younger Bubanj Hum layers (see e. g. Pernicka et al. 1993, 5–7 fig. 1; Whittle 1996, 119; Šljivar et al. 2006, 254–257 and Borić 2009, 209–215, 237–238 with different opinions on this topic). Even if such implements were known earlier in Anatolia and the evidence of casting they would provide is ambiguous for south-eastern Europe, finds such as a casting mould for pins/needles from a Tisza layer in Hódmezővásárhely-Kökénydomb, Hungary, attest to the emergent knowlegde of casting in the Late Neolithic of south-eastern Europe as well (Vulpe 1975; Patay 1984; Pernicka 1990, 37–38; Parzinger 1993, 345).

From sites of the Vinča culture there may also be evidence of smelting (see below), and recent radiocarbon dating shows that the famous mining site of Rudna Glava in Serbia was most likely exploited from at least 5400 cal BC, the beginning of Vinča, until its end around 4600 cal BC (Borić 2009, 194–207, 234–235). We will return to this evidence in more detail below, but it is apparent that during the Late Neolithic – in the Vinča culture and adjacent groups – the potential for proper metallurgy was gradually building up in south-eastern Europe. Vinča also provides important insights into the background against which this process must be seen. The early use of copper and copper minerals as ornaments and pigments reflects a concern with colour and aesthetic values of matter pervading both the domestic and burial domains (Borić 2002; Chapman 2002). Driven by cultural and social needs the earliest mining may have been directed towards copper minerals desirable for their colour (analogous to the earlier use of ochre; Schmandt-Besserat 1980; Weisgerber/Pernicka 1995, 159) and native copper worked into ornaments. It is unlikely, on the other hand, that a limited number of rather small 'tools' initially affected practical activities to the same extent pigments and ornaments did in the symbolic domain. We will probably never know in detail how and why this system evolved into proper metallurgy. However, working in an essentially lithic tradition and thinking in terms of symbolic potential of colour, the transformation of matter's outward appearance by the application of heat (smelting) – possibly in the pyrotechnological context of dark-burnished Vinča ware (Bailey 2000, 224–229; Borić 2009, 206, 237–238) – might have been more manifest than mechanical properties or the development of casting, which only somewhat later came to dominate the symbolic potential of copper by the increase in size and variety of shapes it allowed.

It is at this stage we encounter the large number of often fairly massive copper implements (fig. 2.6), which initially gave rise to the definition of a Eneolithic/Copper Age period in south-eastern Europe. Starting in the south-east – Romania and Bulgaria (Gumelniţa culture/KGK VI), Serbia and Transylvania (late Vinča and Tiszapolgár; Parzinger 1993, 263–265, horizon 8) – the centre of metallurgical activity moved west into the Carpathian Basin in a younger horizon (Bodrogkeresztúr; Parzinger 1993, 265–267, horizon 9; Whittle 1996, 117–119; Bailey 2000, 211–212). There are a large number of different types of shaft-hole hammer axes (e. g. Pločnik and Vidra types; hor. 8) and axe-adzes (e. g. Jászladány type; hor. 9), flat axes and chisels (Schubert 1965; Vulpe 1975; Todorova 1981; Patay 1984; Parzinger 1993, 345–348). It was by reference to such implements that C. Renfrew (1969) argued for an autonomous development of metallurgy. In his classic paper the practice of casting was proven and the earlier hypothesis was discarded that the shaft-hole was produced by drilling (Renfrew 1969, 31). This is important evidence of a well established metallurgical tradition, and from a present-day perspective it seems that Renfrew even underestimated the inventiveness of European metalworkers. There is an evolutionary undertone to his assumption that open moulds were used at this early stage, while in fact some kind of closed mould has to be taken into consideration (Kienlin 2008b; see also chapter 3.4). A total number of 54 copper artefacts known from Early to Late Neolithic contexts are listed by H. Parzinger (1993, 385; including Anatolia) compared to, for example, 55 Pločnik and Vidra type hammer axes and some 227 Jászladány type axe-adzes (Parzinger 1993, 385–388). This gives an impression of just how much metal was in circulation during this period (compare figs. 2.5 and 2.7; see also Ryndina 2009).

Typically, this is quite pure copper, and it is controversial if all or just a part of these objects were still cast from native copper; that is whether copper smelted from its ores was already used at this early stage. Analytical evidence has been taken to support both options (native copper: e. g. Otto/Witter 1952; Junghans/Sangmeister/Schröder 1968; Govedarica/Pernicka/Rittershofer 1995, 266–268 – smelted copper: e. g. Schmitt-Strecker/Begemann 2005, 58 – both: e. g. Renfrew 1969, 29–30; Pernicka 1990, 49–51, 113–114; Pernicka et al. 1993, 13–16). The interpretation

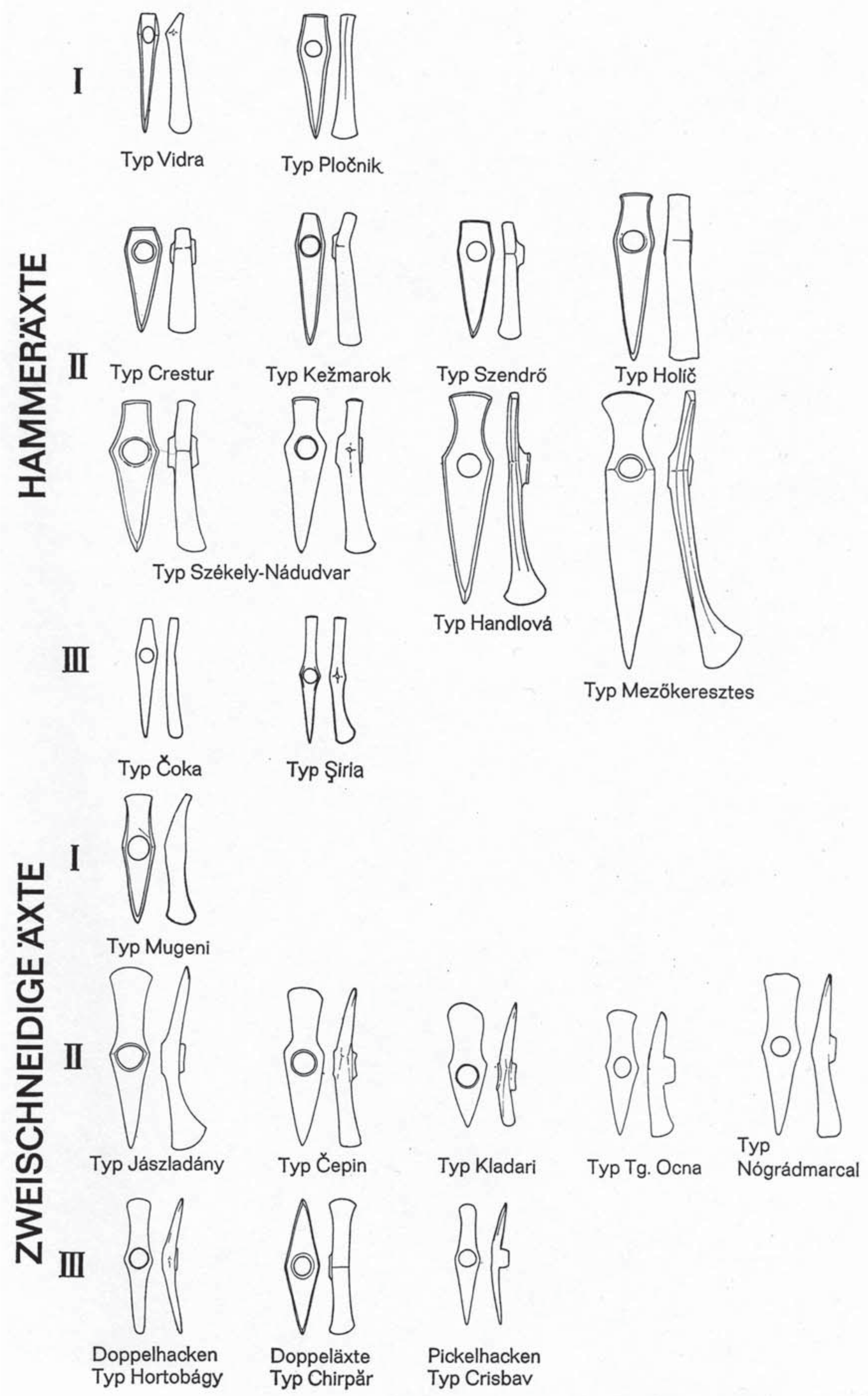


Fig. 2.6: Characteristic shaft-hole implements of the south-eastern European Eneolithic/Copper Age (after Schubert 1965, 276 fig. 1).

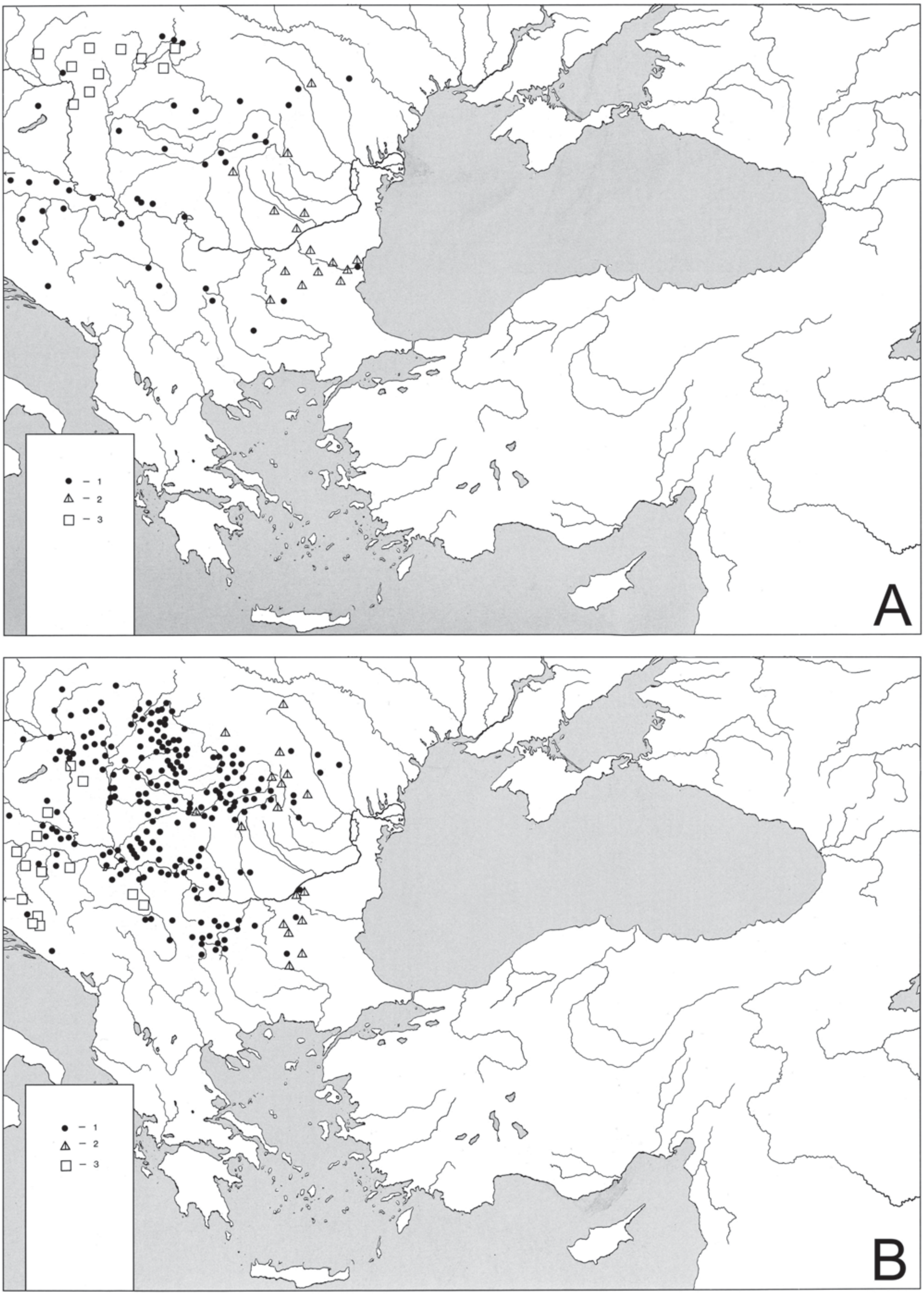


Fig. 2.7: Distribution of Early and Middle Eneolithic/Copper Age copper artefacts in south-eastern Europe (after Parzinger 1993, tabs. 228 and 229); A: Pločnik [1], Vidra [2] and Szendrő [3] type hammer axes of horizon 8; B: Jászladány [1], Tîrgu-Ocna [2] and Kladari [3] type axe-adzes of horizon 9.

of what little evidence there is of early copper smelting is difficult (see below), and there are problems to relating Eneolithic/Copper Age artefacts to the only mines known for sure to have been exploited during the Late Neolithic (Rudna Glava; see above) and Eneolithic/Copper Age (Ai Bunar in Bulgaria, exploited in KGK VI times; Pernicka et al. 1993; Pernicka et al. 1997; Gale et al. 2003 – see discussion below). Still, pure copper may have derived from copper ores depending on ore preparation and smelting technique, and the sheer amount of copper in circulation provides circumstantial evidence that there was extractive metallurgy going on. Most likely this involved the exploitation of several mining districts with no direct evidence of prehistoric workings so far (e. g. Majdanpek; Pernicka et al. 1993).

Apart from stray finds heavy shaft-hole implements, alongside ornaments such as bracelets and pins, are known from settlements (e. g. Pločnik [Serbia]: Chapman 1981, 128–129; Goljamo Delčevo [Bulgaria]: Todorova 1981, 17; 1982, 54–55), graves (e. g. Tiszapolgár-Basatanya [Hungary]: Bognár-Kutzián 1963; Durankulak [Bulgaria]: Todorova 2002) and hoards (e. g. Szeged-Szillér [Hungary]: Patay 1984, tab. 68A). Grave finds and hoards in particular testify to the symbolic dimension copper artefacts had acquired (figs. 2.8 and 2.9; Bailey 2000, 213–218). This should not only be conceptualised in terms of abstract 'wealth' but related to a wider field of material properties and techniques. These include an increasing variability in form as a result of casting and the characteristic 'flash' (Pearce 2007, 20) of copper and increasingly gold too as in the famous Varna cemetery of this period (Ivanov/Avramova 2000; Makkay 1995). Shaft-hole axes are a widespread phenomenon indicating that throughout south-eastern Europe they were 'understood' and drawn upon in the expression of (male) habitus. This should not be simply taken to indicate emerging hierarchies, however, for more importantly the many 'variants' of these implements (Schubert 1965) point to distinct traditions in their production. Clearly, these also offered the potential to be involved in the negotiation of local identities well attested in contemporaneous pottery production (Parkinson 2006, 157–184).

With the end of KGK VI in Bulgaria and somewhat later of Bodrogkeresztúr and others in the Carpathian Basin, there are changes in many aspects of this culture system and metallurgy. In particular the production of heavy copper implements lost much of its attraction in Late Eneolithic/Copper Age Baden etc. times (Vulpe 1975; Todorova 1981; Patay 1984; Schreiner 2007, 78–85). Traditionally this is explained by either historical events, climate change or the exhaustion of oxide ore deposits, i. e. technological incapability. Since there is increasing evidence of the early use of sulphidic copper ores (see below) it is more likely, however, that we witness culture change in the widest sense and a shift in the role of material culture in the social reproduction of Late and Final Eneolithic/Copper Age society (e. g. Whittle 1996, 122–143; Taylor 1999; Bailey 2000, 240–262).

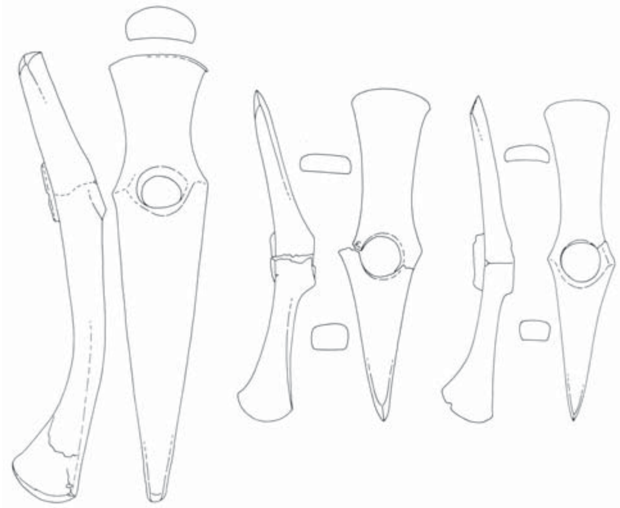


Fig. 2.8: The Eneolithic/Copper Age hoard of Hajdúhadház, Hungary (after Patay 1984, tab. 68C).

Fig. 2.9: The Eneolithic/Copper Age hoard of Szeged-Szillér, Hungary (after Patay 1984, tab. 68A).

2.2.2 The Earliest Copper Artefacts in Central and Northern Europe

In the north alpine region of central Europe there is only a weak reflection of the early development of metallurgy in the Carpathian Basin and on the Balkans. From Neolithic contexts of the late 5th and the early 4th millennium BC no more than about ten to twenty copper objects are known (fig. 2.10). Among them are the well-known disc from the lakeside settlement of Hornstaad-Hörle IA on Lake Constance, two shaft-hole axes and one flat axe from Linz-St. Peter, Austria, and Überlingen on Lake Constance, awls such as the one from Schernau as well as some small copper beads and rings (Matuschik 1997, 97–104 list 3; Bartelheim et al. 2002, 60–63, 71 list 1; Turck 2010, 19–36). The Hornstaad disc has been interpreted as a local imitation of eastern models (e. g. Hlinsko, Stollhof) by use of imported copper or as an import find from a centre of Eneolithic/Copper Age metallurgy in the northern Carpathian Basin

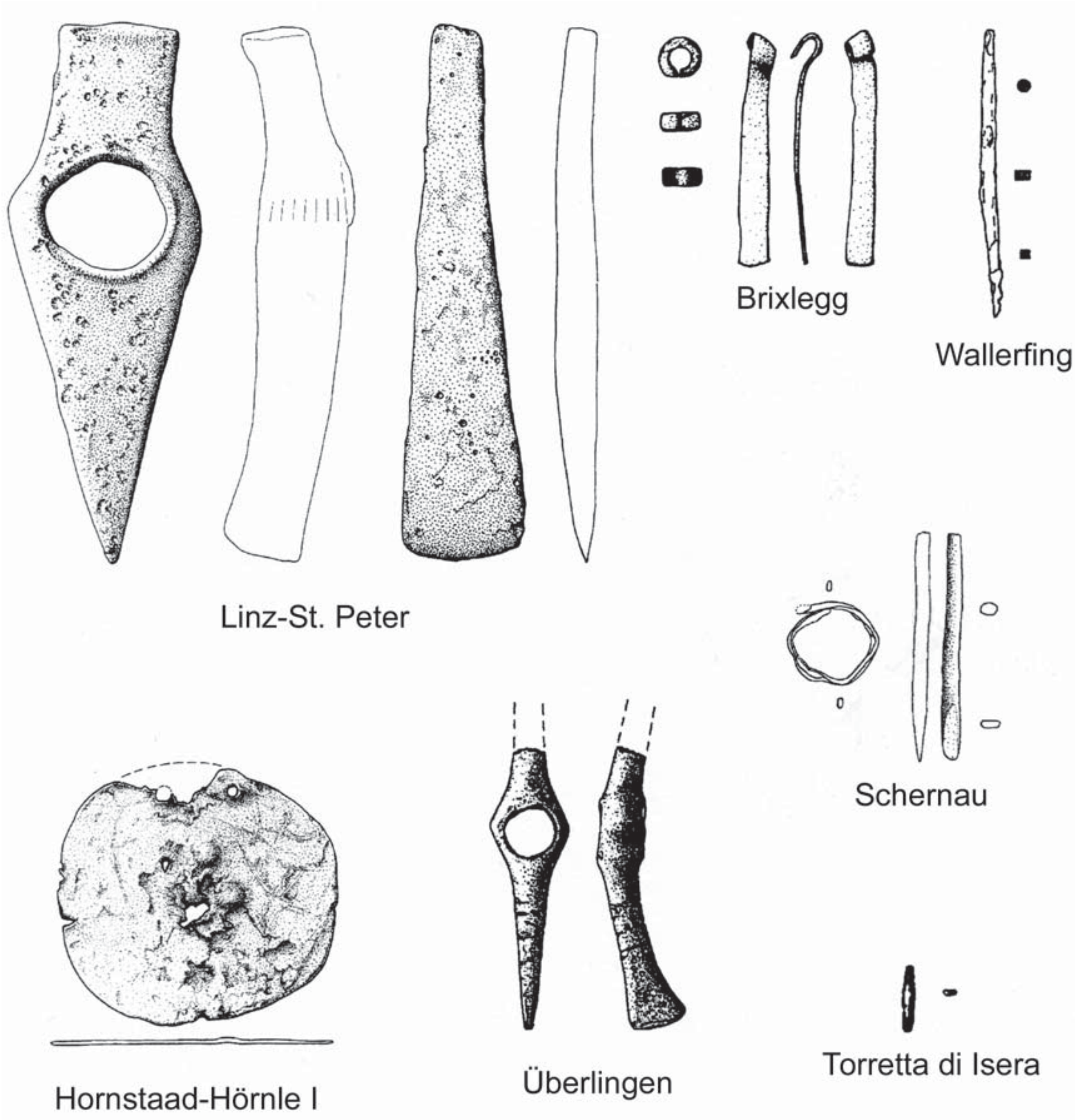


Fig. 2.10: The earliest copper artefacts known from the north alpine region of central Europe (after Bartelheim et al. 2002, 61 fig. 18).

(fig. 2.11).[1] The shaft-hole axes, too, point (further) east to the Copper Age Bodrogkeresztúr culture (Parzinger 1992; Matuschik 1997, 97–102). Until the recent discovery of smelting slag supposedly dating to c. 4500–3900 cal BC at Brixlegg, Austria (Bartelheim et al. 2002; Huijsmans/Krauß/Stibich 2004; Höppner et al. 2005), these early copper finds were thought to be imported from eastern and south-eastern Europe (e. g. Matuschik 1997, 102; Gleser/Schmitz 2001). With regard to the ambiguous evidence from Brixlegg (see below) and the axes mentioned, which clearly derive from the Carpathian Basin, it is likely that this assumption still stands in principle (cf. Höppner et al. 2005, 301–308, 311–312; Gleirscher 2007). It is also clear, that despite obvious contacts with the east exchange of whatever kind did not immediately result in the widespread use of copper objects or in the practice of metallurgy.

It is only somewhat later after about 3800 cal BC with the Late Neolithic (*Jungneolithikum*) Cortaillod, Pfyn, Altheim and Mondsee groups that the number of copper artefacts increases. There are numerous flat axes, daggers, awls and ornaments such as spirals and beads, mainly from the wetland sites along the alpine foothills (Ottaway 1982; Bartelheim et al. 2002, 63–65, 72–75 list 2; Krause 2003, 237–241; Turck 2010, 37–52). In this context there is also good evidence of metalworking with numerous crucibles and copper prills related to the casting process (fig. 2.12; Schlichtherle/Rottländer 1982; Obereder/Pernicka/Ruttkay 1993; Matuschik 1998, 209–212; Bartelheim et al. 2002, 75–76 list 3; Rehren 2004). Extractive metallurgy, on the other hand, has been suggested but is still not well proven. Hence copper is thought either to have been derived from nearby alpine ore deposits and/or to have been imported from south-eastern Europe (e. g. Ottaway 1982, 181–185; Fasnacht 1995c, 184–185; Strahm 1994, 10–12; Matuschik 1998, 239–244). In particular, the eastern alpine mining districts are thought to have been exploited at this time by the population of the Mondsee group, although related

[1] See however Klassen (2010) who argues for an origin of the disc's copper (and the disc itself) from the Alps in northern Italy.

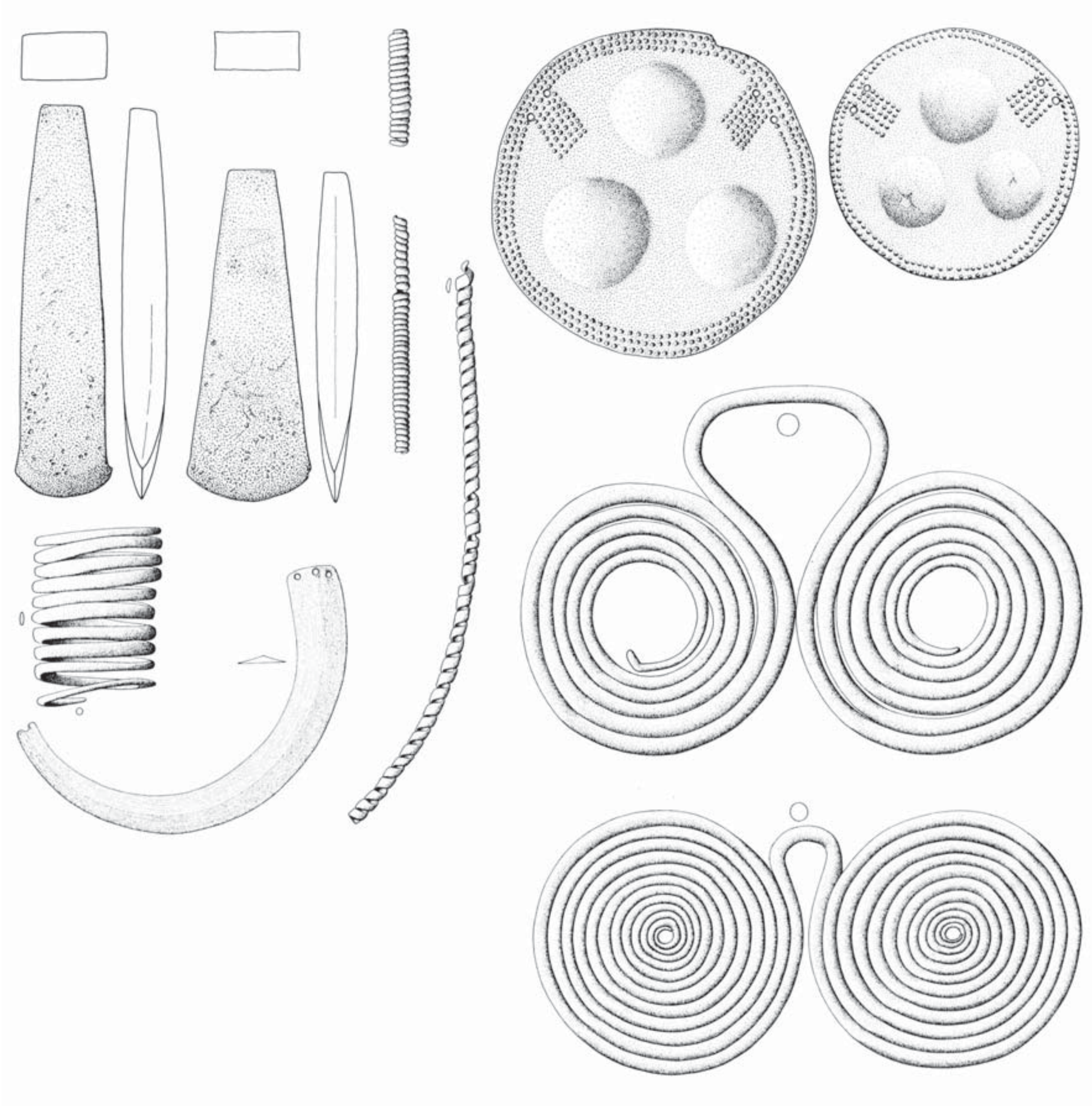


Fig. 2.11: Finds from the Eneolithic/Copper Age hoard of Stollhof, Austria (after Mayer 1977, tab. 117A).

evidence of extractive metallurgy (smelting) from the Götschenberg settlement in the alpine Salzach valley is disputed (Lippert 1992, 41; Moesta 1992, 147–155; contra: Bartelheim et al. 2002, 55, 65). Copper composition may point towards ongoing exchange with the Carpathian Basin instead and indicate the exploitation of ore deposits in the western Carpathians/Slovakian ore mountains (Schreiner 2007).

Comparable to the end of Eneolithic/Copper Age metallurgy in south-eastern Europe, after Pfyn, Altheim and Mondsee there is a significant decrease in the intensity of metalworking during the subsequent Horgen culture and related groups of the local *Spätneolithikum* (Late Neolithic). The existence of at least some Horgen period crucibles indicates that knowledge of metallurgy was not entirely lost (Fasnacht 1989; 1995c). Attempts to explain this 'hiatus' follow the lines of the parallel discussion on the end of the south-eastern European Eneolithic/Copper Age metallurgy mentioned above (e. g. Strahm 1994, 33–34; Kolb 1998; Krause 2003, 239–240).

In northern-central Europe and southern Scandinavia too there is evidence of imported copper artefacts in various Neolithic groups such as Jordanów in Silesia, Brześć-Kujawski in central Poland and from the various subgroups of the Funnel Beaker culture from about 4000 cal BC onwards (Klassen 2000; Müller 2001, 410–417; Krause 2003, 232–237; Roberts 2009a, 466–467). There is some disagreement on precisely which route the earliest copper imports took, e. g. via Baalberge instead of Jordanów (Klassen 2000, 239–255; Müller 2001, 410; cf. Krause 2003, 233). Part of this discussion still relies on ill-conceived diffusionist concepts (e. g. 'Metallurgiedrift', 'Hauptachse' and 'Abzweig'; e. g. Krause 2003, 241–243). It is also unclear where exactly the copper came from. Attempts were made to correlate diachronic change in composition to different provenance areas. Thus, the earliest copper artefacts are thought to have been imported from the Carpathian Basin, and a subsequent move of the supply area in Mondsee times to the eastern Alps is envisaged (Klassen 2000, 235–238; Müller 2001, 413–415; Krause 2003, 233–235). This is controversial since the provenancing

Fig. 2.12: Crucibles of the Late Neolithic Pfyn culture (after Schlichtherle/Rottländer 1982, 64 fig. 3).

of copper on the basis of composition alone poses major problems. The same holds true for claims to a Neolithic exploitation of ore deposits in Scandinavia (e. g. the so-called Riesebusch copper; Klassen/Stürup 2001) and in the eastern central German low mountain ranges (Müller 2001, 413–415). With a general lack of mining traces even for the Bronze Age, evidence derived from composition is at best circumstantial. However, it is noticeable that during the later Neolithic of eastern Germany copper derived from fahlore type deposits makes an early appearance that could tentatively be related to regional sources (Krause 2003, 153–157, 235–237).

In southern Scandinavia the earliest copper imports may even date back to the local Late Mesolithic Ertebølle culture of the second half of the 5th millennium BC (Klassen 2004, 301–335). They are drawn upon by current models to explain the spread of the Neolithic to the coastal areas, through the acceptance of a Copper Age ideology covering large parts of south-eastern and central Europe (e. g. Michelsberg culture) into the Ertebølle territory (cf. Thomas 1988; Klassen 2004, 335–339). With systems of elite exchange supposedly stretching as far as from Brittany to Varna (Klassen 2004, 257–271) this involves considerable extrapolation from the archaeological data (cf. Kienlin 2006a). 'Prestige good system' type models appear to offer greater potential in their classic formulation, focusing on local and regional processes of culture change (e. g. Jennbert 1994; Fischer 2002). Both social dynamics supposedly caused by foreign prestige goods and emergent hierarchies, however, have to be demonstrated rather than assumed. The same holds true for more conventional attempts to link early metal objects and metallurgy to an increase in social complexity (Müller 2001; Krause 2003, 235), in what fundamentally remained an agrarian, kinship-based society far beyond the end of the northern-central European and southern Scandinavian Neolithic.

2.3 The Earliest Evidence of Mining

Mining historically is by no means an achievement related to metallurgy, nor must it be conceived of in purely functional terms. There is ample evidence throughout Europe of mining for flint and stone already in the Neolithic (e. g. Körlin/Weisgerber 2006). While some of these workings were obviously aimed at superior raw material for the production of weapons or tools, there are cases in which deep mining was unnecessary in strictly functional terms of the mechanical properties of the stone or flint exploited, and/or the raw materials obtained by mining apparently were set apart for special socially motivated needs (e. g. Topping 2005; Barber 2006; Oliva 2006). Symbolism clearly was involved in the Mesolithic and Neolithic use of haematite as well and in the early mining for this reddish iron oxide mineral (e. g. Pernicka 1990, 49–50; Goldenberg et al. 2003; Ottaway/Roberts 2008, 203). Attention paid to social and symbolic aspects of early mining, both in the operation of mining activities and in the uses of its products, is a relatively recent phenomenon (e. g. Edmonds 1995; Knapp/Pigott/Herbert 1998; Topping/Lynott 2005; Blakely 2006); but a development with important bearings on the early history of metallurgy as well (see above). The excavations and scientific studies of the mines of Rudna Glava in Serbia and Ai Bunar in Bulgaria are an excellent example, as the work, carried out over more than thirty years, provides an impression of the complexity of the early mining for copper and its minerals, their working and distribution in south-eastern Europe.

Unlike many other copper ore deposits potentially exploited in prehistory, from Rudna Glava and Ai Bunar there is direct archaeological evidence of Late Neolithic and Eneolithic/Copper Age mining in the form of Vinča and Karanovo VI-Gumelniţa pottery recovered from the mines themselves (Rudna Glava: Jovanović/Ottaway 1976; Jovanović 1982; 1996; 1999; Ottaway 1994, 53–55; Weisgerber/Pernicka 1995, 161–163; Ai Bunar: Chernykh 1978; Ottaway 1994, 55–57; Weisgerber/Pernicka 1995, 165–166; Bailey 2000, 215–217; cf. Parzinger 1993, 345–346). Radiocarbon dates confirm this chronology and allow us to be more precise about the duration of mining activities. Rudna Glava, for example, was shown to have been exploited not only during late Vinča times but from the very beginning of Vinča about 5400 cal BC (Borić 2009, 194–207). In both Rudna Glava and Ai Bunar there are indications that small-scale mining activities may have begun much earlier than the Late Neolitic/Copper Age, although this period certainly saw the most intense mining activities (Gale et al. 2003, 156–161; Borić 2009, 234–238). Mining was done by following ore

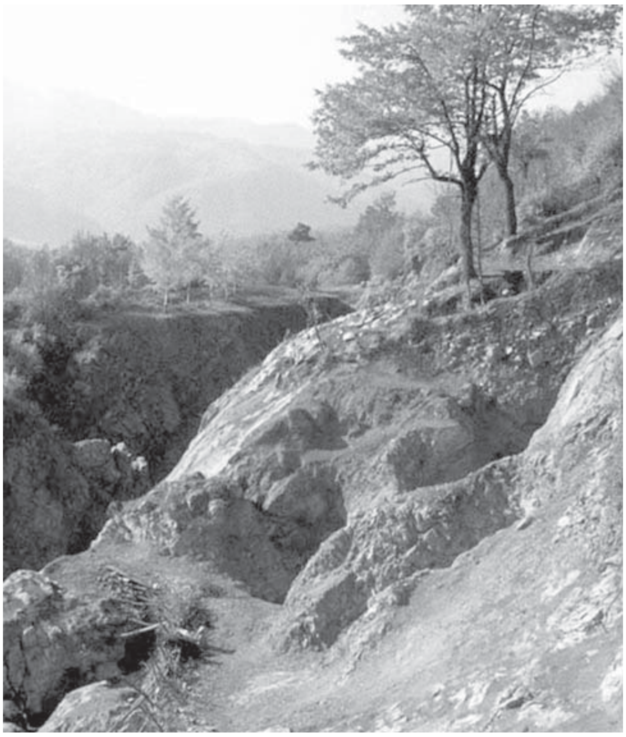


Fig. 2.13: Mining traces at Rudna Glava in Serbia (after Borić 2009, 201 fig. 3).

veins down from the surface (fig. 2.13). Typically, it went down some metres only but occasionally a depth of 20 m to 30 m was reached, resulting in irregular cavities (Rudna Glava) and *Pingen*-like structures of up to 100 m length (Ai Bunar). Mining tools include (grooved) hammerstones and antler picks, and there is evidence of firesetting. Several copper shaft-hole axes found at Ai Bunar were interpreted as mining tools as well but their low hardness would certainly have limited practical use (see chapter 5.1). From Rudna Glava, in particular, there is evidence of (ritual) hoarding in the mines with pottery, stone and bone tools as well as ore left behind by the miners (fig. 2.14; Jovanović 1999). In both Rudna Glava and Ai Bunar the trenches were backfilled – perhaps in an attempt to appease supernatural powers after the removal of the earth's wealth (Weisgerber/Pernicka 1995, 166). Some crushing and beneficiation of the ore was carried out but there is no evidence of further processing in the vicinity of the mines themselves (Ottaway 1994, 56). This finding, which is in line with other early mining districts throughout the Old World (e. g. Chalcolithic Feinan, Jordan: Weisgerber 2003, 79–81; Early Bronze Age Aegean: Catapotis 2007), was described in terms of redistribution (Ottaway 1981; 1994, 179–181). An alternative explanation may refer to either technical or cultural and symbolic reasons for a spatial separation of mining, smelting and metalworking (Bailey 2000, 215–217; Weisgerber 2004, 26–27; Hauptmann 2007, 123; Catapotis 2007, 214–219 'conspicuous production'; see also Doonan et al. 2007, 112–117).

This latter finding requires a move to contemporaneous settlements from which both copper minerals/ores and copper objects are known (e. g. Belovode close to Rudna Glava or sites in Stara Zagora near Ai Bunar; Gale et al. 2003, 156–159; Borić 2009, 207–209). Specifically from some Vinča settlements such as Pločnik and Belovode there is evidence of thermally altered copper minerals and slags interpreted as the result of extractive metallurgy (Šljivar et al. 2006; Radivojević 2007; Borić 2009, 207–215; Radivojević et al. 2010). We have to return to this point below since the identification of smelting slag is a difficult matter. But even if the production of copper may be proven in some cases the overall picture is much more complex than simply a spatial extension of the *chaîne opératoire* from mine (exploitation/beneficiation) to settlement (smelting/working). Firstly, mining at both Rudna Glava and Ai Bunar in part predates the earliest production of massive copper implements. Hence, at least initially most copper minerals came to the settlements for use as ornaments and pigments. More importantly, lead isotope analyses indicate that stratified copper minerals from Late Neolithic Vinča settlements in Serbia did not originate from Rudna Glava (Pernicka et al. 1993, 25–38). The opposite may be true for Bulgarian settlement sites and Ai Bunar (Gale et al. 2003, 156–161), although in Bulgaria as well the use of additional ore sources is likely, which are as yet unidentified. At least in Serbia it is quite clear that there were more mines in operation than just Rudna Glava (e. g. Ždrelo; Jacanović/Šljivar 2003; Šljivar et al. 2006; Borić 2009; Radivojević et al. 2010). The way copper minerals took for use as pigments or smelting was more complex than just 'down-the-line' from mine to settlement, and it was regionally specific. Similarly, hardly any copper objects analysed from Serbia and Bulgaria are consistent with having been made of copper from Rudna Glava and Ai Bunar respectively (Pernicka 1990, 113; Pernicka et al. 1993, 25–38; Weisgerber/Pernicka 1995, 163; Pernicka et al. 1997, 143–146; Gale et al. 2003, 159–161, 168–170).

In both areas a range of different ore sources was exploited, and the exchange networks for copper minerals and copper were complex and manifold. Some settlements can be shown to have drawn on a number of different ore deposits, and the same applies to Varna and the tell site of Dolnoslav (thought to be a 'cult place' rather than a settlement; cf. however Whittle 1996, 89) – both thought to have carried ritual connotations for the inhabitants of a wider territory (Gale et al. 2003, 162–164, 168–169). Variability in compositional and lead isotope data and therefore probably in the origin of the copper used can be found throughout the Copper and Early Bronze Ages (e. g. Pernicka et al. 1997, 143–146; Schmitt-Strecker/Begemann 2005). It may be taken to support the notion that early mining for copper minerals (pigments) and ores for smelting was small-scale and seasonal, not an elite-driven effort but most likely carried out in a communal or kinship-based mode of operation (see chapter 8.5).

2.4 The Transformation of Matter: Smelting

In the beginning of south-eastern and central European metallurgy, high-purity copper was used (Junghans/

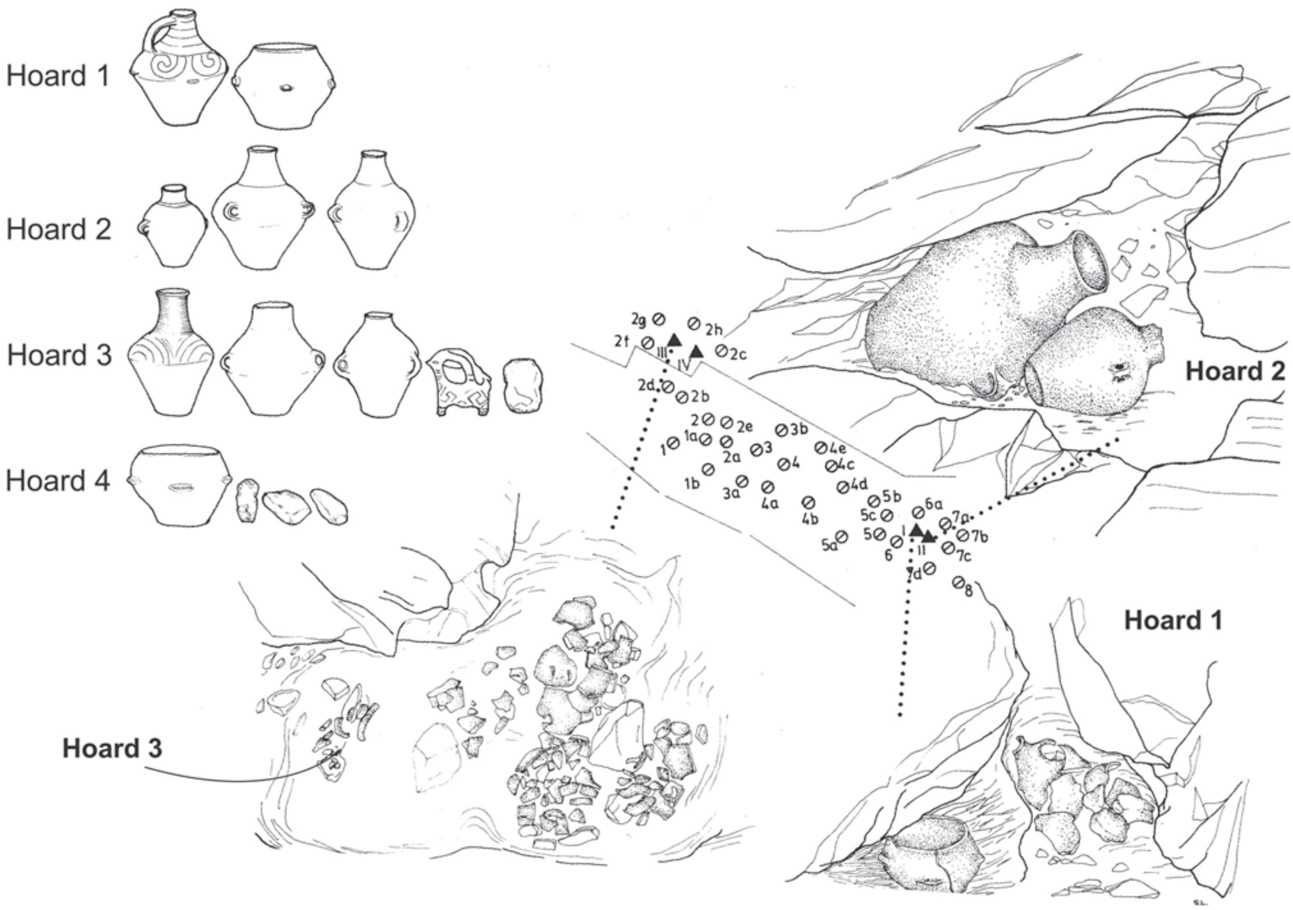


Fig. 2.14: Vinča culture hoards at the mining site of Rudna Glava (after Borić 2009, 204 fig. 7).

Sangmeister/Schröder 1968) derived from either native copper or the smelting of oxidic copper ores (copper carbonate minerals). Later on this *Reinkupfer* was increasingly replaced by arsenical copper (Sangmeister 1971; Schubert 1981; Pernicka 1990, 49–52) thought to be easier to work and to offer superior mechanical properties (e. g. improved casting properties and ductility, higher hardness after cold work; e. g. Charles 1967, 21; Coghlan 1975, 81; Hauptmann/Weisgerber 1985, 30; Northover 1989; 1998, 117–118; see however the discussion in chapter 7.5). With typically rather low arsenic contents up to about 2 % arsenical copper – in a central and south-eastern European context – is not an alloy, but derives from the smelting of copper ores associated with arsenic bearing minerals (for summaries of this debate see Northover 1989; Lechtman 1996; Lechtman/Klein 1999; Ottaway/Roberts 2008, 208–209; Kienlin 2008a, 251–280; Roberts/Thornton/Pigott 2009, 1015, 1017–1018).[2] There is evidence from various Late Neolitic/Eneolithic groups that copper high in arsenic produced this way was deliberately chosen for the production of daggers while axes were cast from copper with lower arsenic contents. This choice points towards the importance of colour in the production of weapons, instead of mechanical properties important for tools; the silvery appearance arsenic provided to the daggers instead of higher hardness for the axes (e. g. Craddock 1980; Ottaway 1982; Budd/Ottaway 1995; Matuschik 1998; Keesmann/Moreno Onorato 1999; Müller et al. 2007). Only much later in the Early Bronze Age arsenical copper was replaced by fahlore copper and other copper varieties derived from sulphidic ores (Kienlin 2008a; see below in chapter 7). This sequence is often interpreted in terms of geology and technological progress. The earliest miners and smelters are thought to have worked the upper, oxidised regions of their mines with relatively simple technology while the exploitation of the deeper, sulphidic ore bodies is thought to have required advances both in mining and smelting techniques (e. g. Hauptmann/Weisgerber 1985; Strahm 1994, 33–34; Ottaway 1994, 16–18).

This standard model is derived from a simplified geological view of the ore bodies in question and from early modern sources such as Georg Agricola's (1978 [1556]) description of the smelting of sulphidic copper ores in a multi-stage process involving the roasting of the ore prior to smelting (fig. 2.15; e. g. Bachmann 2003). It is this process we encounter in the Late Bronze Age eastern Alps (see chapter 6.2; e. g. Cierny et al. 2004; Herdits/Löcker 2004; Giumlia-Mair 2005, 287–288), but the model itself is simplistic and evolutionist. There is increasing evidence for a much more nuanced picture with the earliest working of sulphidic ores

[2] For a potential example to the contrary, the production of speiss as an alloying component in the production of arsenical copper/bronze in Iran, see Thornton/Rehren/Pigott (2009, 314–315).

Der Röſtſtadel A. Die Hölzer B. Das Erz C. Kegelförmiger Hauſe D. Das Waſſergerinne E.

Fig. 2.15: Installations for the roasting of ore prior to smelting (Agricola 1978 [1556], 237).

reaching back far into the Eneolithic/Copper Age (Shennan 1995, 298–300; Moesta 2004, 270–271; Hauptmann 2007, 130–133; Hauptmann 2008, 128–130; Roberts/Thornton/Pigott 2009, 1017). Until recently sulphur was not analysed for in analytical programmes, and trace elements are of limited value as a guide to the ore type used. Early Bronze Age fahlore copper typically has high impurity levels indicating the use of this specific type of sulphidic ores (e. g. Early Bronze Age Salez type axes; Krause 1988, 214–245), and compositional data may be taken to imply the early use of such copper prior to the Early Bronze Age in some parts of central Europe (e. g. 'diluted' fahlore copper in the Late/Final Neolithic of eastern central Germany; Krause 2003, 153–157, 235–237). But there is also high-purity copper from the Early Bronze Age which only metallography can relate to sulphidic ores by demonstrating the presence of copper sulphide inclusions (e. g. in Neyruz type axes; Kienlin/Bischoff/Opielka 2006; Kienlin 2008a, 187–215). Similarly, it is by metallography that Eneolithic/Copper Age objects can be shown on occasion to contain sulphide inclusions. This points towards the early use of (mixed oxidic and) sulphidic ores (e. g. Preßlinger 1996/97). In western Europe the early pre-Bronze Age use of sulphidic ore deposits is well attested (Ross Island: Ixer/Pattrick 2003; O'Brien 2004, 451–477; Cabrières/southern France: Bourgarit et al. 2003; Bourgarit 2007). For the earliest metalworking horizon of central and south-eastern Europe the evidence of smelting is more ambiguous and often disputed. But even so there is some information to be gained from the (potential) mines themselves and the scientific analysis of installations and residues related to the smelting process.

From the 5th millennium BC Vinča sites of Belovode, Pločnik and Selevac in Serbia there is evidence of thermally altered copper carbonate minerals or 'slags' thought to relate to smelting activities (Glumac/Tringham 1990, 550–554, 562; Glumac/Todd 1991a, 157–160; 1991b; Šljivar et al. 2006, 252–257; cf. Borić 2009). Typically, these are small pieces and it is difficult to distinguish proper slag from thermally altered ore/minerals, heated for whatever reason other than smelting copper from it. Interpretation is also often unclear in terms of smelting slags versus slags from casting copper and forging activities (see, for example, Bartelheim et al. 2002, 62 on the Selevac evidence). Similarly, related installations such as small 'melting pots' or bottomless vessels/'chimneys' thought to have served as furnaces (e. g. from Belovode, Plocnik and Divostion; Šljivar et al. 2006, 253, 256; cf. Borić 2009, 234–238) often have unclear signs of actual heating. It is only with a careful re-examination of the archaeometallurgical remains, that proper evidence for copper smelting in Vinča contexts becomes available (e. g. Belovode: Radivojević 2007; Radivojević et al. 2010). If in fact smelting is demonstrated,

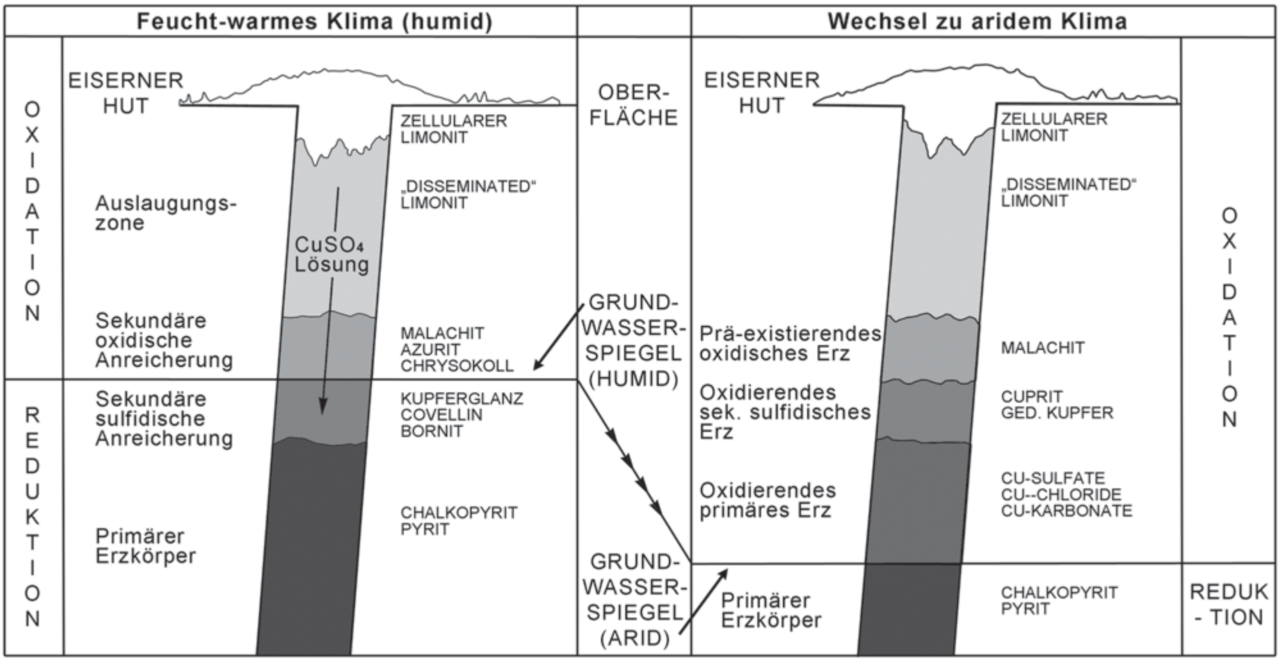


Fig. 2.16: The formation and dynamics of the secondary enrichment zone in copper ore deposits; note in particular the dependency of the processes involved on climate conditions (after Strahm/Hauptmann 2009, 123 fig. 5).

this was apparently done in ephemeral installations; an approach to early smelting found throughout the Old World relying on highly concentrated, self-fluxing ores to produce small copper prills entrapped in a matrix of partially smelted ore and slag (Hauptmann 2007, 125–130; 2008, 131–135; Roberts/Thornton/Pigott 2009, 1017; Radivojević et al. 2010).

Using a combination of metallography demonstrating copper sulphide inclusions in artefacts and the scientific analysis of refractory ceramics, this crucible-type smelting technique was shown to have worked well on sulphidic copper ores already in the second half of the 5th millennium BC Bulgarian Gumelniţa and Varna groups (Ryndina/Indenbaum/Kolosova 1999). At about the same time of the Münchshöfen culture (c. 4500–3900 cal BC) from the site of Brixlegg-Mariahilfberg, Tyrolia, what is thought the earliest evidence of smelting in the north alpine region is recorded (Bartelheim et al. 2002; Huijsmans/Krauß/Stibich 2004; Höppner et al. 2005). This would make for a rapid spread of smelting from south-eastern to central Europe and/or roughly contemporaneous local experimentation. In Brixlegg, too, drawing on nearby fahlore deposits already at this early stage sulphidic copper ore was used (Bartelheim et al. 2002, 54–56). There is a problem, however, with the dating of the metallurgical remains in question which might also belong to the younger Pfyn, Altheim and Mondsee horizon on this site (c. 3900–3600 cal BC; see Gleirscher 2007, 102–104 and Turck 2010, 20–22 for critical re-evaluation). On the other hand, previously accepted evidence of Mondsee period oxide ore smelting at the alpine Götschenberg site (Moesta 1992; Ottaway/Roberts 2008, 206) is now debated by the authors of the Brixlegg study (Bartelheim et al. 2002, 55, 65). So the overall situation is not yet clear.

Smelting evidence from the (late) 5th and 4th millennium BC tends to be problematic because of the bad archaeological visibility of the processes and installations involved. But early experimentation with both oxidic and sulphidic ores clearly has to be taken into consideration. The smelting of both types of ore are not clear cut technological stages. Hardly any mine follows the ideal of oxide ores on top and sulphidic ones underneath (fig. 2.16). This is why early miners hit on different types of copper minerals that, typically but by no means every time, may have been distinguished and sorted out by colour, weight or density. Experimental work and analyses show why this did not pose fundamental problems upon subsequent smelting. It is exactly the 'primitive' nature of early oxide ore smelting under rather oxidizing conditions that allowed for the incorporation of sulphidic ores as well, in a kind of 'self-roasting' one stage process, without causing failure of the entire process (e. g. Lorscheider/Maass/Steiniger 2003; Timberlake 2007, 33–34; Hauptmann 2007, 132; Thornton/Rehren/Pigott 2009, 314). Knowledge of advanced medieval and modern smelting techniques (e. g. Strahm 1994, 5–8) is a poor guide to the earliest stages of the development of this process.

3
Traditions in the Making: Aspects of the Production of Eneolithic/Copper Age Shaft-Hole Axes

Much work has been done both archaeologically and scientifically on the earliest occurrence of copper artefacts, analysing their origin and spread, the ore deposits likely to have been exploited and the development of methods of smelting employed. Obviously, these are central problems in the study of early metallurgy, and the transmission of copper objects and metallurgical knowledge is described in two parallel strands: a) from simple artefacts produced by hammering and annealing locally available native copper or copper imported from adjacent areas; to a broader spectrum of more sophisticated forms produced by casting for display or symbolic uses; and somewhat later for superior weapons or implements; and b) in terms of provenance, the early history of mining and the development of specialised knowledge involved in smelting different types of copper ore. Both aspects are closely linked to an interest in expanding networks of communication and exchange through which knowledge of metallurgy, of new types of copper and copper alloys was transmitted, and copper or somewhat later tin became available to communities not in command of such resources themselves. In this context, the development of methods of casting and working copper often is seen as a matter of course, and even recently it has been claimed that: "[...] simple metalworking techniques were highly localised and passed between individuals, thus making studies of technological transmission using metallographic and chemical analyses of metal artefacts extremely difficult." (Roberts/Thornton/Pigott 2009, 1016).

Yet it is precisely in the context of local metalworking that abstract 'influences' or inventions from abroad were translated into practice, and there was technological choice that resulted in clearly discernible regional traditions. However, rather than focusing on composition as a guide to provenance this requires an approach that centres on cognitive aspects of early metallurgy and seeks to highlight some of the underlying reasons of the technological choices taken. These include the knowledge gained by prehistoric metalworkers of different types of copper and copper alloys, corresponding modifications to their *chaînes opératoires*, regional or long-term variation in the methods of casting and forging applied as well as the effect this had on the properties of the copper objects produced.

It is suggested that metallography (see appendix I) can contribute to these aims, and for this study it was possible for the first time to examine the microstructures of a larger series of Eneolithic/Copper Age implements (see Kienlin 2008a for a corresponding study on Early Bronze Age material). Drawing on this data, in this chapter aspects of the production of Eneolithic/Copper Age hammer axes and axe-adzes are discussed. These are not the earliest copper objects in the Carpathian Basin and south-eastern Europe but they provide the opportunity for an in-depth understanding of a particular tradition of Eneolithic/Copper Age metalworking that put heavy emphasis on the production of massive copper implements, desirable maybe primarily for their extravagant shape and their sheer size and weight. Particular attention will be paid to the methods of casting, which during this period had substantial influence on the subsequent forging of the axes and their performance upon use. In chapter 4 the further development and transformation of this tradition will be traced into more recent periods using metallographic data from flat axes.

3.1 Hammer Axes and Axe-Adzes: Chronology, Distribution and Data of this Study

The numerous copper shaft-hole implements known from south-eastern Europe during the 19th century already provided the basis of attempts to define a 'Copper Age' or 'Eneolithic' period (see chapter 2.1). Subsequently, the large variety of such weapons or tools was divided into ever more sophisticated schemes with many different types or variants according to their formal characteristics. Their development and more precise chronological position were discussed, and distribution patterns were taken to reflect various centres of production. Basically, however, there are two large groups (fig. 2.6): Hammer axes, as their name implies, have one arm which is formed like an axe while the opposite one is shorter and without a cutting edge it is best described as fulfilling a hammer-like function. The second group of so-called axe-adzes consists of artefacts whose one arm is in the form of an axe while the other one is set at a right angle to form an adze-like implement (in German *zweischneidige Äxte* or rather more fittingly *kreuzschneidige Äxte*).

J. Driehaus (1952) and F. Schubert (1965) suggested the outlines of a classification system that in principle is

still in use today. Modifications and further subdivisions were suggested by the authors of the 'Prähistorische Bronzefunde' series, in particular by M. Novotná (1970), A. Vulpe (1975), E. F. Mayer (1977), H. Todorova (1981), P. Patay (1984), J. Říhovský (1992) and Z. Žeravica (1993) who dealt with the axes from Slovakia, Romania, Austria, Bulgaria, Hungary, Moravia and parts of former Yugoslavia respectively. Formal characteristics employed in these 'typologies', that are typically perceived as reflecting some kind of change or progress through time as well (fig. 3.1), include size, the presence or absence of a shaft-hole 'lip' or rim, i. e. a prolongation or reinforcement of the shaft-hole, the relative length of the axe arm and hammer arm/adze arm respectively as well as the bending – if any – of both arms or just one of them in longitudinal cross-section.

For the occurrence of comparable implements outside south-eastern Europe the reader is referred to L. Klassen (2000; 2004) and N. Boroffka (2009a). To the north and north-west, including the North German Plain, Poland and Denmark, it is likely that copper and massive copper implements were imported into local Neolithic groups from the Carpathian Basin (see chapter 2.2.2; e. g. Lutz/Matuschik/Pernicka 1997; Klassen/Pernicka 1998; Klassen 2004, 69–72, fig. 48; Gedl 2004, 22–23). To the east, on the other hand, including the eastern Mediterranean, the Caucasus and Central Asia there obviously existed the tradition of the production of copper (and later on bronze) shaft-hole axes, which is thought to be related to the south-eastern European one (e. g. Schreiner 2007, 72–89; Boroffka 2009a, 254). In the area under discussion in the present study, the Carpathian Basin and adjacent regions, massive copper shaft-hole implements occur in a variety of culture groups locally designated as Late Neolithic, Eneolithic or Copper Age such as (late) Vinča, Tiszapolgár, Bodrogkeresztúr, Cucuteni (A/B) or Kodžadermen-Gumelniţa-Karanovo VI (Parzinger 1993, 263–267, hor. 8/9). Starting earlier on the eastern Balkans and on the lower Danube than in the Carpathian Basin, in absolute terms this Eneolithic/Copper Age development roughly covers the second half of the 5th millennium BC and the early 4th millennium BC (see chapter 2.1).

Samples for metallographic examination could be obtained from 17 hammer axes of Pločnik, Crestur, Kežmarok, Székely-Nádudvar and Şiria types (fig. 3.2; see appendix II). Pločnik type hammer axes for typological reasons of their 'plump' appearance and their occurrence in the Karbuna hoard, Moldova, dated to Tripolje A are thought to be among the earliest shaft-hole implements of south-eastern Europe. The precise position of the 'hoards' from Pločnik in the Vinča sequence is debatable, but apparently rather late (see chapter 2.2.1). Better evidence of Pločnik type hammer axes, too, typically points to later Gumelniţa and Cucuteni A3/4 as well as from Tiszapolgár times onwards (Novotná 1970, 19–21; Vulpe 1975, 19–21; Mayer 1977, 9, 15–17; Todorova 1981, 35–39, Patay 1984, 38–39; Žeravica 1993, 5–6; Parzinger 1993, 263–265, 345–347). Their main area of distribution is in the former Yugoslavia, i. e. Serbia, Croatia and Bosnia, the Banat region and Transylvania with less frequent finds further east as well as to the north and north-west of the Carpathian Basin (fig. 2.7A). It is from the latter area that three of our samples come from (nos. 62, 144 and 153). The other three Pločnik type axes sampled are of unknown origin (sample nos. 85, 100 and 184). These pieces are in the Vienna collections and judging from the wide catchment area of the museum, based upon the former Austrian-Hungarian empire, this indicates that they may come from the main distribution of such implements in the southern part of the Carpathian Basin and on the Balkans.

Axes with a rim or enforcement on one or both sides of the shaft-hole are thought to be typologically 'younger', and there is a tendency towards an elongation of the axe arm. Such features may be seen on hammer axes of Crestur and Kežmarok types with one sample each (sample no. 96 of unknown origin and sample no. 141 from the north-western fringes of the Carpathian Basin). A larger number of six axes of the related type Székely-Nádudvar could be examined, whose main distribution is in the northern Tisza area and Transylvania but extends well beyond this region as well, for example into both western Hungary and Slovakia (e. g. Novotná 1970, 23–24; Patay 1984, 55–56, tab. 63A). Again, among the axes sampled there are pieces of unknown origin, which are most likely from somewhere in the Hungary in general or from the Danube region (sample nos. 82, 183, 185 and 196; see also SAM database in Krause 2003). The axe with sample no. 45 from Linz may come from a hoard (together with a flat axe of type Szakálhát; Mayer 1977, 10 no. 9, 50 no. 111), and the axe sample no. 176 originates from the surroundings of Budapest. Although typologically 'younger' than Pločnik type axes such forms clearly start in the same broad horizon 8 according to H. Parzinger (1993, 345–347), for a Crestur type axe was found in a (younger) Tiszapolgár culture grave of the Tibava cemetery in Slovakia (Novotná 1970, 22–23; Vulpe 1975, 25; Mayer 1977, 15; Patay 1984, 41–42). A date corresponding to Parzinger's (1993, 347–348) horizon 9 (with possibly an earlier beginning in horizon 8) can be derived for Székely-Nádudvar type hammer axes from their formal similarity with Jászladány type axe-adzes. In the finds of Szendrő (hoard?)[3], Mezősas (hoard?/grave? fig. 3.3)[4] and Szeged-Sziller (hoard; fig. 2.9)[5] such hammer axes (or fragments thereof) possibly were associated amongst other forms with Split and Szakálhát type flat axes as well as with a Jászladány type axe-adze. The latter are known from grave finds to date to Bodrogkeresztúr times (Novotná 1970, 23–24; Vulpe 1975, 26–28; Mayer 1977, 15–16, 50–52; Patay 1984, 47–55; Žeravica 1993, 6–9). This is also the date and cultural affiliation of the last hammer axe form sampled, type Şiria, that is known,

[3] Patay 1984, 33 no. 95 (flat axe type Felsőgalla/Szakálhát; Mayer 1977, 15, 52: type Split), 44 no. 180 (hammer axe type Szendrő) and 83 no. 464 (fragment of Jászladány type axe-adze, secondary use as hammer; Mayer 1977, 15, 52: possibly fragment of Székely-Nádudvar type hammer axe).

[4] Patay 1984, 22 no. 12 (chisel), 26 no. 36 (flat axe type Szakálhát) and 61 no. 276 (hammer axe type Agniţa; Mayer 1977, 15, 51: hammer axe type Székely-Nádudvar).

[5] Patay 1984, 21 no. 10 (chisel), 26 no. 31 (flat axe type Szakálhát; Mayer 1977, 15: flat axe type Split), 79 no. 424 (axe-adze type Jászladány), 83 no. 466 (axe-adze type Jászladány, secondary use as hammer; Mayer 1977, 15: possibly fragment of Székely-Nádudvar type hammer axe).

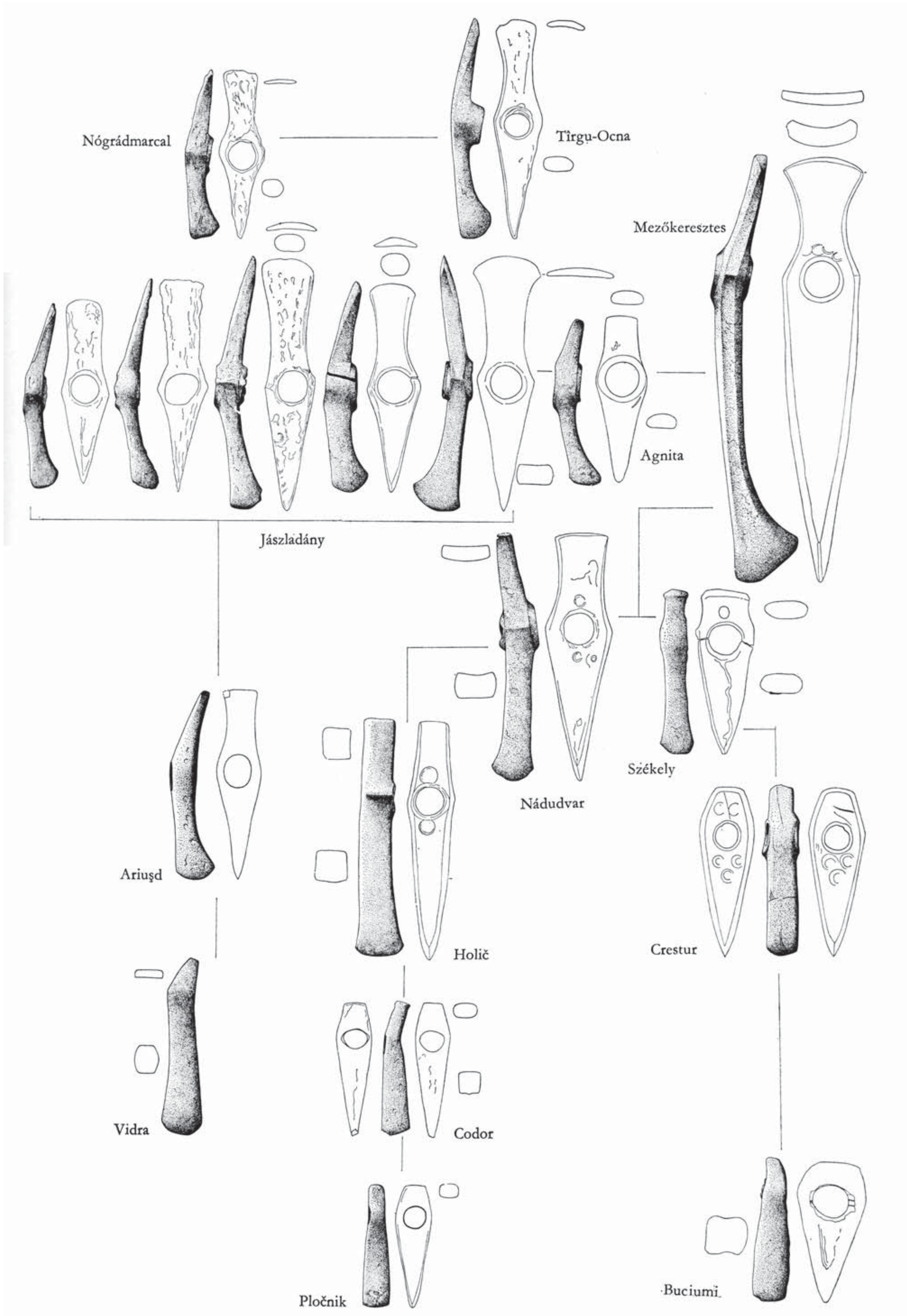


Fig. 3.1: Typology and supposed development of Eneolithic/Copper Age shaft-hole axes in Romania (after Vulpe 1975, 15 fig. 1).

Fig. 3.2: Types of Eneolithic/Copper Age hammer axes examined in this study (from left to right: Pločnik [Říhovský 1992, 22 no. 1, tab. 1.1], Crestur [Mayer 1977, 9 no. 5, tab. 1.5], Kežmarok [Říhovský 1992, 25 no. 7, tab. 1.7], Székely-Nádudvar [Patay 1984, 51 no. 223, tab. 17.223] and Şiria [Patay 1984, 65 no. 299, tab. 26.299]).

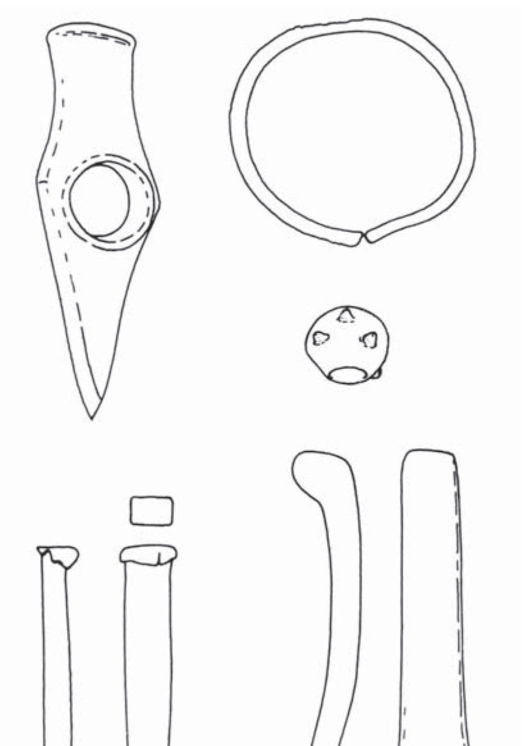


Fig. 3.3: The Eneolithic/Copper Age grave or hoard find from Mezősas, Hungary (after Patay 1984, tab. 67A).

for example, from graves of the Bodrogkeresztúr culture at Kiskőrös (Patay 1984, 64 no. 284) and Tiszavalk (fig. 3.4; Patay 1984, 65 no. 311). Most Şiria type hammer axes are known from the distribution area of the Middle Copper Age Bodrogkeresztúr culture, but they are also known beyond this region (Vulpe 1975, 32–33; Mayer 1977, 15–16; Patay 1984, 63–66; Parzinger 1993, 347–348; Matuschik 1997). Three axes of this type could be sampled, two of them from Hungary or the Danube region in general (sample nos. 181 and 190). The remaining one is from north-western Hungary (sample no. 182).

In total 17 axe-adzes of Mugeni/Ariuşd, Jászladány, Kladari and Nógrádmarcal types could be sampled for this study (fig. 3.5; see appendix II). Jászladány type axes form the most numerous sub-group or type of Eneolithic/Copper Age axe-adzes known. Likewise with 12 pieces examined they represent the largest group of samples available. They were first named by J. Driehaus (1952) after a find from the Copper Age cemetery of Jászladány in the Hungarian district of Szolnok. In its broadest terms this type includes axe-adzes of rather different size and weight whose arms are of roughly the same length, with a rather broad adze arm and a curved cutting edge of the axe arm. The shaft-hole is set in the middle of the artefact which, apart from the different functions of both arms, gives these implements a symmetrical appearance. Both on the upper and lower side there is a more or less marked socket-like protrusion or rim around the shaft-hole. Besides these general characteristics there is some variation in the details of size and shape. This is why authors such as A. Vulpe (1975, 37–48) or P. Patay (1984, 67–89) distinguished (many) different variants of

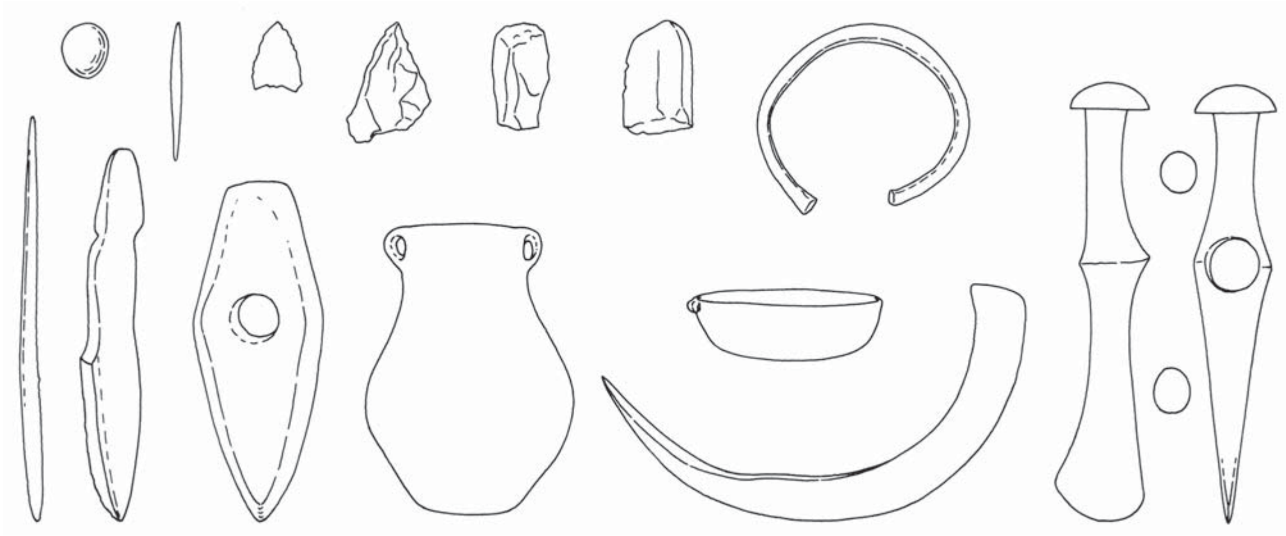


Fig. 3.4: Finds from grave no. 29 of the Bodrogkeresztúr culture at Tiszavalk-Kenderföld (after Patay 1984, tab. 66D).

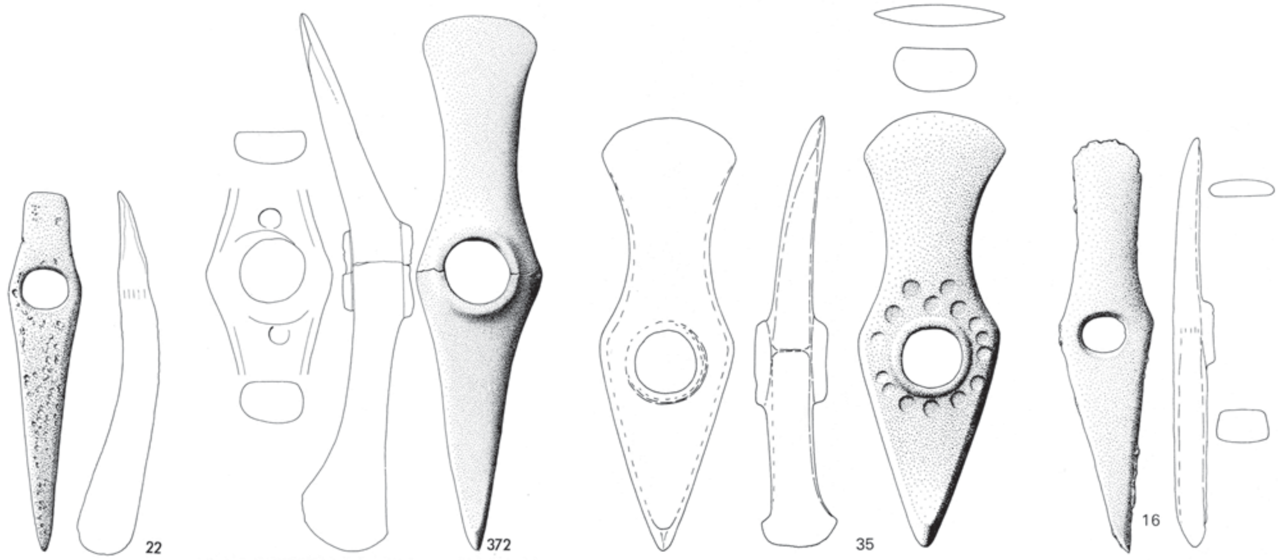


Fig. 3.5: Types of Eneolithic/Copper Age axe-adzes examined in this study (from left to right: Mugeni/Ariușd [Mayer 1977, 11 no. 22, tab. 2.22], Jászladány [Patay 1984, 74 no. 372, tab. 34.372], Kladari [Žeravica 1993, 18 no. 35, tab. 4.35] and Nógrádmarcal [Říhovský 1992, 31 no. 16, tab. 3.16]).

Jászladány type axes. The formal differences used to define such variants do not, however, seem to indicate systematic differences in the chronological position of the artefacts in question (Vulpe 1975, 46–47; Patay 1984, 86, 88).

Jászladány type axe-adzes are known from large parts of south-eastern Europe (fig. 2.7B). In particular there are concentrations of finds in the great Hungarian plain, east of the Tisza river in north-eastern and eastern Hungary, in neighbouring Romanian Transylvania and further south in the Banat region. Outside the Carpathian Basin the number of Jászladány axes decreases along the Danube valley and towards the Black Sea, but they are well known from the north-western Balkans. To the west their distribution covers the area between Tisza and Danube as well as Transdanubia and reaches Austria, Moravia and Bohemia with a smaller number of pieces. Further Jászladány type axes are known alongside other types of shaft-hole implements as import finds from various parts of central and northern Europe (Novotná 1970, 25–27; Vulpe 1975, 46–47; Mayer 1977, 16–17; Patay 1984, 87–88; Parzinger 1993, 347).

The origin of most of the axes sampled is unknown or given in general terms only such as Hungary or the Danube region (sample nos. 98, 105, 107, 175, 177, 178, 179, 189 and 206). Such provenance is also manifest from both the general distribution of Jászladány type axes and from the history of the Vienna collections in which these pieces are kept. Furthermore, in some cases there is competing information on provenance, such as for sample nos. 175 and 179, which

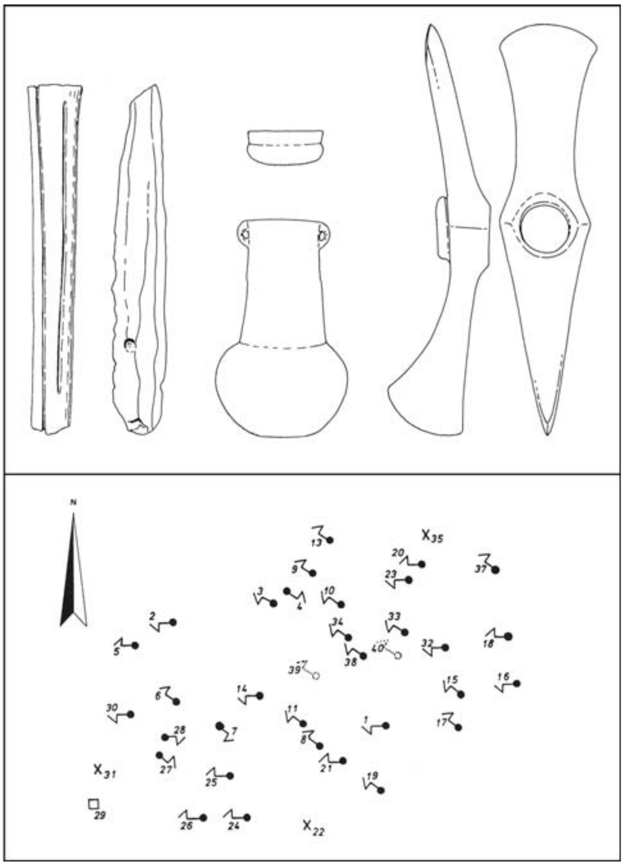


Fig. 3.6: The eponymous cemetery of Jászladány, Hungary; Jászladány type axe from grave no. 18 (after Patay 1984, tab. 67B; Lichter 2001, 345 fig. 154).

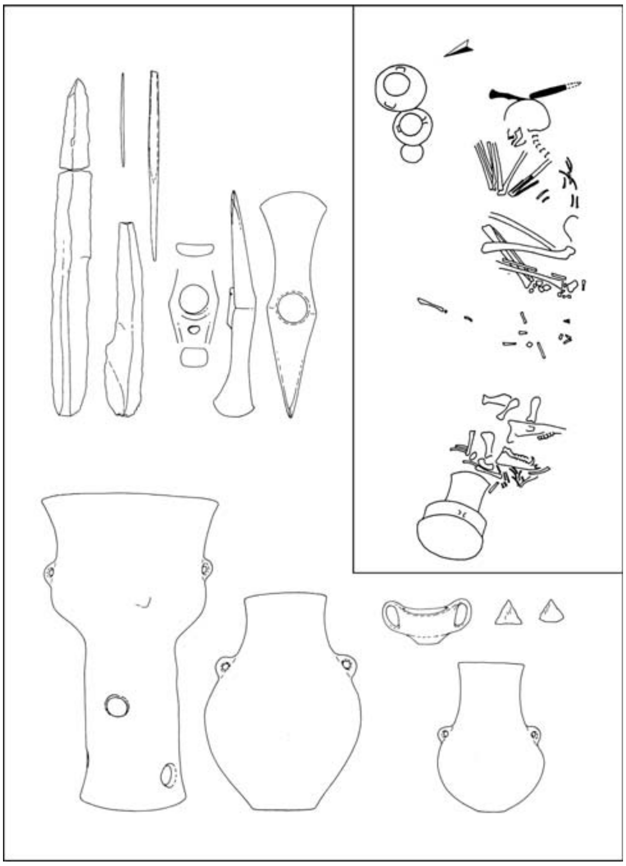


Fig. 3.7: Cemetery of Magyarhomorog-Kónyadomb, Hungary; grave no. 46 of the Bodrogkeresztúr culture with a Jászladány type axe (after Lichter 2001, 336 fig. 148).

is given with either 'Hungary' in general (Patay 1984, 71 no. 335, 76 no. 389) or more precisely as Banská Bystrica in today's Slovakia (SAM database in Krause 2003, no. 3647) and Osijek in Croatia (SAM no. 3778). More detailed and reliable information is available for few pieces only. The axe with sample no. 48 possibly comes from Upper Austria although the precise location of its discovery is unknown (Mayer 1977, 12 no. 26), axe no. 138 is possibly from Plaveč in today's Slovakia (Říhovský 1992, 34 no. 23), and sample no. 205 is from Sopron-Bánfalva in western Hungary (Patay 1984, 75 no. 385).

Whenever possible two samples were taken of each axe (indicated by appendices -1/-2 to the sample number), both from its axe-arm and from its adze-arm to allow comparison. This wasn't possible for axe no. 98, which is a fragment with part of the axe-arm missing. Similarly, axe no. 189 is a fragment with the axe-arm lost and its remains later on reused as a hammer. In these cases there is only one sample each from the adze-arm of the implement. From the axe with sample no. 179 two samples were taken, but one of them proved too tiny for preparation. The remaining one, actually sample no. 179-1, is the one from the axe arm.

Axe-adzes of the Jászladány type were uncovered in a number of cemeteries belonging to the Bodrogkeresztúr culture, for example in grave no. 18 of the eponymous cemetery of Jászladány (fig. 3.6) and in grave no. 46 of the Bodrogkeresztúr culture at Magyarhomorog-Kónyadomb (fig. 3.7), both in Hungary. By their occurrence in graves of this group they are firmly linked to the Middle Copper Age in Hungarian terminology (*Hochkupferzeit*; Patay 1984, 7 fig. 1, 86–87) with possible beginnings in the Early Copper Age Tiszapolgár culture. Additional evidence comes from the association with other types of copper implements in occasional hoard finds (e. g. Szeged-Szillér: fig. 2.9). These also point to the time of the Bodrogkeresztúr culture and contemporaneous groups in adjacent areas (Vulpe 1975, 46–47; Mayer 1977, 16; Patay 1984, 86–87; Parzinger 1993, 347–348). Drawing on radiocarbon dates we are talking about the late 5th and early 4th millennium for Tiszapolgár and Bodrogkeresztúr as well as neighbouring Neolithic groups from the north alpine region of central Europe (see chapter 2.1).

A smaller number of samples could be taken from axe-adzes of Mugeni/Ariuşd (Vulpe 1975, 35–37; Mayer 1977, 11; Patay 1984, 67), Kladari and Nógrádmarcal types. Sample no. 91 comes from a Mugeni/Ariuşd type axe-adze of unknown origin. Axes of this form for typological reasons are thought to be the earliest axe-adzes in circulation, and in fact they are found in Cucuteni A and Tiszapolgár context. Younger pieces of this type are found in association with Jászladány type axes and date to Bodrogkeresztúr times. Correspondingly, their distribution shows a concentration in Transylvania, Serbia and western Bulgaria – probably

their area of origin – while their occurrence further west is thought to reflect the younger horizon of their use and distribution (Vulpe 1975, 36–37; Mayer 1977, 16; Patay 1984, 67; Žeravica 1993, 11–12; Parzinger 1993, 348).

Two samples were taken from Kladari type axe-adzes, one of them of unknown origin (sample no. 94; due to bad preservation of the axe-arm there is a sample of the adze-arm only), the other one from Bosnia (sample no. 180). In the eponymous hoard of Kladari-Karavid in Bosnia an axe-adze of this type was found in association with a flat axe of type Stollhof, variant Hartberg and a number of Gurnitz type flat axes (Žeravica 1993, 17 no. 31, 50 no. 133, 53 nos. 144–146; horizon 1 as defined for this study, see chapter 4.1.1). Their similarity to and associations with Jászladány type axes underline the assignment of Kladari type axe-adzes to the Bodrogkeresztúr horizon (e. g. Balaton-Lasinja in Transdanubia). Their main distribution area is on the western Balkans, in Dalmatia and Bosnia, with occasional finds further north in western Hungary (fig. 2.7B; Vulpe 1975, 48; Mayer 1977, 16; Patay 1984, 89–90; Žeravica 1993, 17–20; Parzinger 1993, 348).

Finally, there are two samples of Nógrádmarcal type axe-adzes from the hoard of Malé Leváre in Slovakia (sample no. 52; adze-arm damaged, hence sample of axe-arm only) and another one from the Czech republic (sample no. 118). Nógrádmarcal type axes are closely related to Jászladány ones with the exception that the bending of their arms is less marked, and there is no 'lip' or rim around the shaft-hole on their upper side. Hence, typology suggests roughly the same date of both forms, and their mutually exclusive distribution might support this assumption. Nógrádmarcal type axes cover northern Hungary and Slovakia where proper Jászladány type axes are rarely found (Vulpe 1975, 51–52; Patay 1984, 90–92). Malé Leváre (fig. 3.8), too, is typically assigned to the Bodrogkeresztúr etc. horizon on grounds of the axe-adze and spiral contained (e. g. Parzinger 1993, 265–267, 347–348; Matuschik 1996, 8; Zimmermann 2007, 28–31). But there is a discussion surrounding the flat axe found in this hoard that seems to be leading up to the somewhat younger Altheim type axes. A somewhat younger date than Bodrogkeresztúr has also been suggested for the dagger found in Malé Leváre (Novotná 1970, 14 no. 2, 16–17, 25–26 no. 125; Patay 1984, 92). This discussion will be taken up in chapter 4.1.2 with reference to the dating of flat axes. Still, it should be noted that some kind of post-Bodrogkeresztúr date for type Nógrádmarcal or Malé Leváre etc. – in the sense of Hunyadi-halom etc. (Patay 1984, 92) – clearly implies that the type and hoard in question predate anything specific Late Eneolithic/Copper Age in the sense of Baden (-Boleráz) proper by a considerable period of time (see chapter 2.1). All axe types discussed in this chapter are clearly Early to Middle Copper Age – Hungarian terminology – in the sense of Tiszapolgár and Bodrogkeresztúr as well as neighbouring Late Neolithic/Eneolithic groups further west such as late Lengyel, Ludanice or Balaton-Lasinja (fig. 2.1).

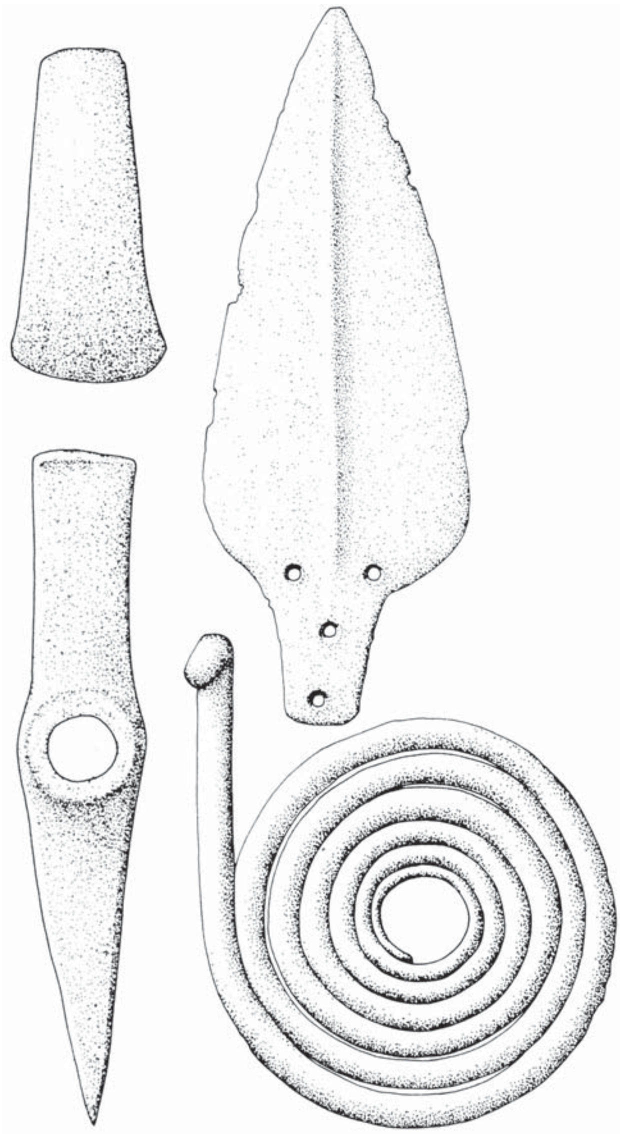


Fig. 3.8: The Eneolithic/Copper Age hoard of Malé Leváre, Slovakia (after Novotná 1970, tab. 48B).

3.2 Casting and Working I: The Metallographic Evidence of the Hammer Axes

Given that the axes of this group have a wide distribution throughout the Carpathian Basin and cover a period of several hundred years the overall impression provided by the present samples points towards a remarkable stability in basic production parameters. Clearly, the hammer axes considered do not represent the very beginnings of metallurgy in south-eastern Europe (see chapter 2.2.1). But their production certainly is typical of the rise of proper Eneolithic/Copper Age metallurgy. One might expect then, at least initially, some variation in the technological choices taken along the *chaîne opératoire* of casting and working copper into these rather massive implements. However, this is not the case. There are indications of varying 'quality' achieved or care given in casting but the overall procedure already was fairly standardised. Both knowledge of the production steps required and skill involved in the actual casting and working were already well established. In order

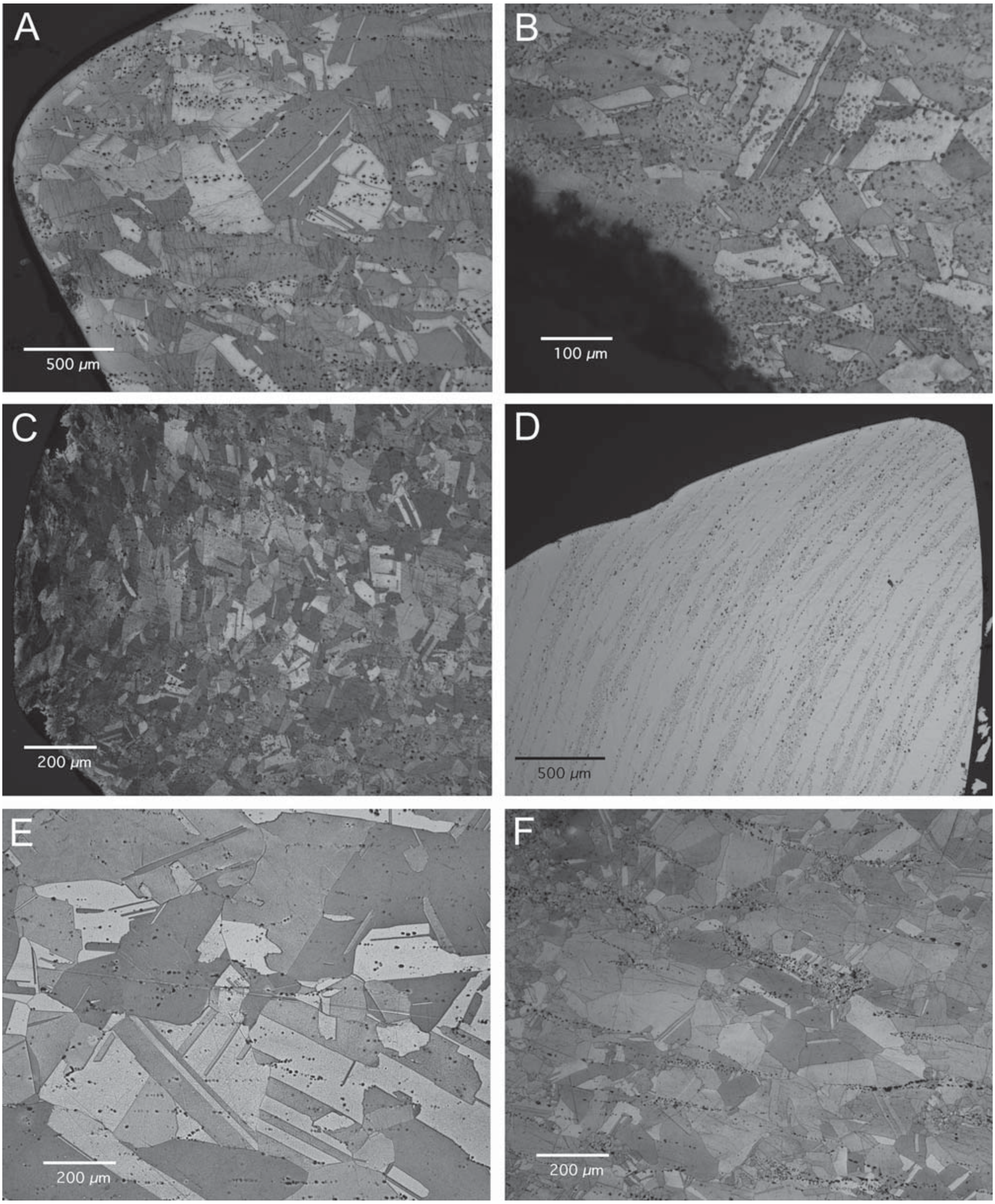


Fig. 3.9: Characteristic microstructures of Eneolithic/Copper Age hammer axes examined for this study (A: sample no. 45; B: sample no. 176; C: sample no. 182 [note use wear, left at the tip of the sample]; D: sample no. 62 [note the heavily deformed ($Cu+Cu_2O$)-eutectic]; E: sample no. 141; F: sample no. 183).

to understand the emergence of this metalworking tradition we have to turn to the wider context of Eneolithic/Copper Age society below (see chapter 5).

All samples in this group show a fully recrystallised microstructure (figs. 3.9 and 3.10 M8; see also the corresponding tables in appendix II). Strictly speaking, therefore, we can derive no information on the casting process from the copper matrix, and previously various techniques including cold working native copper were suggested for the production of Eneolithic/Copper Age shaft-hole implements such as the ones in question (e. g.

Sample no.	Porosity, phases and inhomogeneities						Production steps						Final cold work					Total working		
	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20
Eneolithic/Copper Age hammer axes (type)																				
45 (Székely-Nádudvar)	0	2.27%	a	(x)	0	0	0	xx	xx	x	xx	xx	0	0	0	0%	0	x	-	<50%
62 (Pločnik)	0	3.66%	a	x	0	0	0	xx	xx	x	xx	xx	0	(x)	0	0%?	x	xx	-	>50%
82 (Székely-Nádudvar)	x	0.27%	(a)	0	0	0	0	xx	xx	x	xx	xx	0	(x)	0	0%?	x?	x?	-	<<50%?
85 (Pločnik)	0	1.2%	a	(x)	0	0	0	xx	xx	x	xx	xx	0	(x)	0	0%?	x?	x	-	<50%
96 (Crestur)	(x)	3.84%	a	x	0	0	0	xx	(xx)	x	xx	xx	0	0	0	0%	0	xx	-	>50%
100 (Pločnik)	(x)	1.4%	(b)	0?	0	0	0	xx	(xx)	x	xx	xx	0	(x)	x	0%?	x	x?	-	<<50%?
141 (Kežmarok)	0	0.88%	a	(x)	0	0	0	xx	xx	x	xx	xx	0	0	0	0%	0	(x)	-	<<50%
144 (Pločnik)	0	0.65%	a	(x)	0	0	0	xx	xx	x	xx	xx	0	0	0	0%	0	x	-	~50%?
153 (Pločnik)	0	0.47%	a	(x)	0	0	0	xx	xx	x	xx	xx	0	(x)	0	0%?	x?	(x)	-	<50%
176 (Székely-Nádudvar)	0	7.56%	a	x	0	(x)	0	xx	xx	x	x	x	(x)?	x	(x)?	20-30%?	x	x	x	~50%
181 (Şiria)	0	1.04%	a	(x)	0	0	0	xx	xx	x	xx	xx	0	(x)	0	0%?	x	x	-	~50?
182 (Şiria)	0	3.38%	a	x	0	0	0	xx	xx	x	xx	xx	0	(x)	0	0%?	x	xx	-	>50%
183 (Székely-Nádudvar)	0	1.1%	a	(x)	0	0	0	xx	xx	x	xx	xx	0	(x)	0	0%?	(x)	x	-	~50?%
184 (Pločnik)	0	2.19%	a	(x)	0	0	0	xx	xx	x	xx	xx	0	0	0	0%	0	(x)	-	<<50%
185 (Székely-Nádudvar)	0	0.5%	a	0?	0	0	0	xx	xx	x	xx	xx	0	(x)	0	0%?	(x)	(x)	-	<<50%
190 (Şiria)	0	0.34%	a	0	0	0	0	xx	(xx)	x	xx	xx	0	(x)	0	0%?	(x)	(x)	-	<50%
196 (Székely-Nádudvar)	0	0.6%	a	(x)	0	0	0	xx	xx	x	xx	xx	0	0	0	0%	0	(x)	-	<<50%

Fig. 3.10: Microstructural features of the Eneolithic/Copper Age hammer axes examined for this study. M1: porosity (0 = none/hardly any; x = occasionally; xx = frequent) – M2: oxides (% of sample area) – M3: kind of oxides (a = [$Cu+Cu_2O$]-eutectic; b = particles) – M4: influence of oxides on hardness (0 = none; x = yes/assumed) – M5: further phases (0 = none/hardly any; x = present) – M6: coring in copper matrix (0 = none/hardly any; x = weak residual coring; xx = heavily cored) – M7: casting grains (0 = none; x = present) – M8: recrystallisation (0 = none; x = partial; xx = complete) – M9: twinning (0 = none; x = frequent; xx = in most/all grains of sample area) – M10: production steps after casting (0 = none; x = as-cast, cold worked, or: cold worked, annealed, or: hot worked; xx = cold worked, annealed, cold worked, or: hot worked, final cold work) – M11: homogenisation (0 = none; x = partial; xx = complete) – M12: intensity of annealing/application of heat (0 = equi-axed grains; x: equi-axed grains, partly homogenised; xx: equi-axed grains, homogenised) – M13: deformation of grains (0 = none; x = moderate; xx = heavily deformed) – M14: deformation of twins (0 = none; x = moderate; xx = heavily deformed) – M15: strain lines (0 = none; x = one system; xx = duplex slip) – M16: strength of final cold work (% reduction in thickness, close to the cutting edge/tip of the sample) – M17: wear traces (0 = none; x = additional deformation at the cutting edge due to moderate use; xx = tip of the sample heavily deformed due to heavy use) – M18: deformation/breakage of porosity/oxides (0 = none; x = moderate; xx = heavily deformed) – M19: deformation of coring (0 = none; x = moderate; xx = heavily deformed) – M20: estimated total reduction in thickness (% reduction in thickness, close to the cutting edge/tip of the sample).

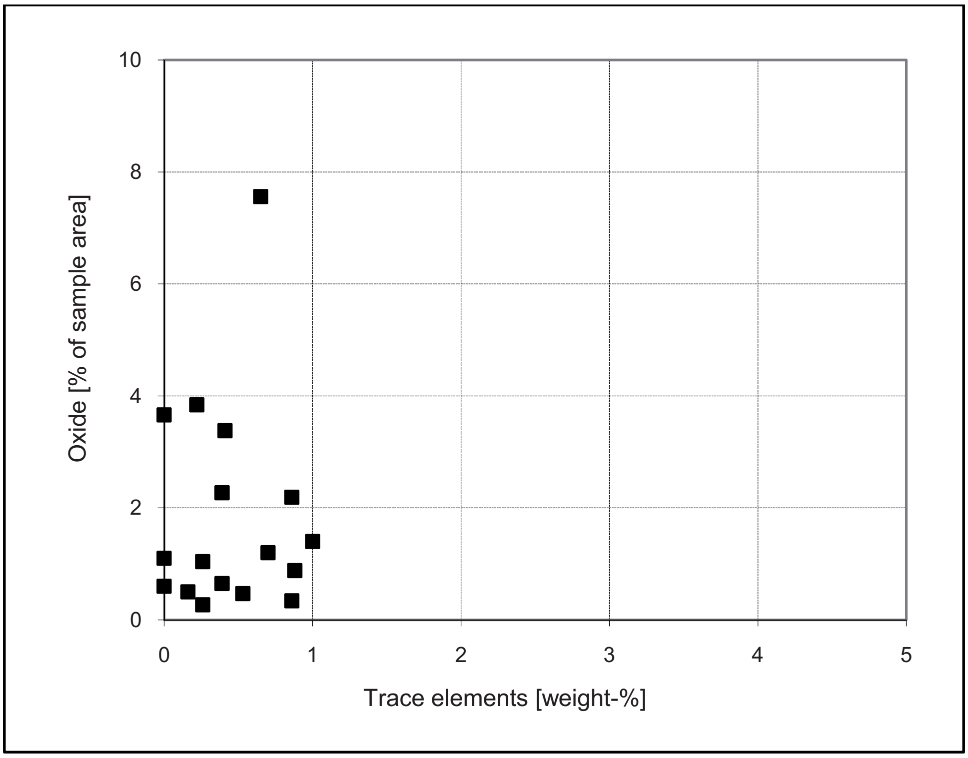


Fig. 3.11: Composition and frequency of oxide inclusions in the Eneolithic/Copper Age hammer axes examined.

Mayer 1977, 12–14; Boroffka 2009a, 251–252). Their complex shape including the shaft-hole suggests casting as opposed to the extremely labourious hammering and drilling from a lump of (native) copper, but this is only an inconclusive common sense argument. Instead, it is the oxide inclusions which bring light to this question (fig. 3.9). Oxygen pick-up occurs while the copper is molten and upon pouring into the mould. The presence of copper oxide therefore provides unequivocal evidence of casting as the first step of production (see also chapters 3.4 and 3.5).

Copper oxide, which is identifiably by its reddish colour under polarised light, is present in all the axes. Its amount – given in percent of sample area – is highly variable, and ranges from 0.27 % in sample no. 82 to 7.56 % in sample no. 176 (figs. 3.10 M2 and 3.11). The latter piece clearly has an exceptionally high copper oxide content even in this group of Eneolithic/Copper Age axes. From a modern perspective it would be regarded a spoiled cast indicating very poor control over oxygen pick-up and casting atmosphere (Schumann 1991; Scott 1991; Kienlin 2008a, appendix I). Much the same may be said of a group of axes with oxide contents in the 2 % to 4 % range (sample nos. 45, 62, 96, 182 and 184), while on the other hand there are also quite a number of axes with less than 1 % of copper oxide (e. g. sample nos. 82, 153, 185 and 190). The mean copper oxide content therefore is at 1.84 %.

Oxygen pick-up by the molten copper is thought to deteriorate the casting quality due to gas evolution upon solidification (i. e. increased porosity), and the presence of oxides supposedly embrittles copper objects (cf. Ottaway 1994, 129–138; Kienlin 2008a, 255–262). From this perspective virtually all Eneolithic/Copper Age axes discussed fall short of modern expectations and castings de-oxidised by use of phosphorus containing additives. In fact, the rather high variability in oxide contents may indicate some difficulties to maintain control over gas absorption during melting and casting. Alternatively, it may reflect technological choice in that varying degrees of attention were paid to this aspect of the casting process (see also chapter 5.1). However, at least sample no. 176 clearly was a poor cast even by Eneolithic/Copper Age standards, and to a lesser extent this might also apply to the other axes with above-average oxide contents. The number of castings spoiled by gas evolution, porosity and incompletely filled moulds, which were subsequently remolten, is beyond the grasp of the archaeologist. Presumably it was rather high, and with a piece like sample no. 176 we may only encounter the tip of an iceberg of failed attempts at casting such massive copper implements. On the other hand, such artefacts are surviving in quite substantial numbers, and the expertise involved in their production on a regular basis at all must not be underestimated. Even sample no. 176 alongside all the axes in the 2 % to 4 % oxide range received the standard working (see below). It is likely, therefore, that quite high oxygen pick-up and oxide content was acceptable without causing intolerable problems upon casting and finishing the axes. Variability in oxide contents may point to different levels of skill involved, systematic differences in attention paid or just to non-recurring difficulties encountered during a specific casting

process. Generally speaking, we must beware not to mistake variability and restricted control over casting atmosphere (from a perspective of modern standards) for 'primitive' casting technique (see also below for a similar argument with regard to the supposed influence of trace elements on oxide content and casting quality).

After casting the axes were subject to a heat treatment sufficient both in terms of temperature and duration to erase the original casting grains and to allow the growth of new so-called equiaxed grains with straight grain boundaries (fig. 3.9). With generally low impurity contents of up to about 1 % (fig. 3.12) inhomogeneities of the as-cast microstructure certainly were of limited intensity. However, both experimental data and metallography of prehistoric objects show that coring occurs down to very low trace element and alloying contents (e. g. arsenic and tin: Buchwald/Leisner 1990; Budd 1991a; Northover 1996; Lechtman 1996; Wang/Ottaway 2004). After casting most of the axes very likely had a slightly cored, dendritic as-cast microstructure. As a consequence of rapid cooling which prevented equilibrium conditions, this is fairly typical of prehistoric castings involving 'primitive' traditional technology in general (Kienlin 2008a), and in sample no. 176 weak residual coring can still be seen overlying the recrystallised microstructure. Experimental work with arsenical copper shows that with temperatures between 300 °C and 500 °C, extensive recrystallisation appears within half an hour. For an additional homogenisation of the microstructure over the same period of time, temperatures of more than 600 °C are necessary (Budd 1991b; Schumann 1991). Since all other samples are fully homogenised (fig. 3.10 M11/12) a rather high intensity and prolonged heating can be inferred as the standard procedure for this group of hammer axes.

In all samples there is ample evidence of twinning in most grains, i. e. different orientations in crystal texture that emerged upon recrystallisation (figs. 3.9 and 3.10 M9). For the characteristic twin bands to occur a deformation is required either while the object is hot (i. e. during recrystallisation itself: hot work) or prior to the heat treatment (i. e. cold work followed by annealing). Since both processes result in essentially the same microstructure it is impossible to use metallographic data in a straightforward way to distinguish hot work from cold work followed by annealing (Northover 1989; Schumann 1991; Scott 1991; Kienlin 2008a, appendix I). In any case, however, the presence of twins in the whole sample area proves that one way or the other the axes were forged to give them their final shape and surface finish after casting. This working may have involved the removal of casting seams or any surface defects after casting as well giving the blade its final outline and sharpening the cutting edge.

While twinning must not be used to directly infer deformation rates (Schumann 1991; Scott 1991; Kienlin 2008a, appendix I) other evidence can help to be more precise about the intensity of working. Oxide inclusions sometimes were heavily deformed from their original position along grain boundaries in the as-cast state into layer-like structures (fig. 3.9), and porosity too was affected by working (fig. 3.10 M18). In sample nos. 82 and 96 there is corrosion along what may have been porosity remaining from the casting process. Typically, however, the axes in question have a very dense microstructure (fig. 3.10 M1). Due to gas evolution and shrinkage upon solidification initially there certainly was a higher amount of porosity that was subsequently closed by forging. Its traces might still be found in the axes' bodies that were less heavily affected by working. This feature is beyond the reach of the present samples, but it is shown, for example, by X-ray or new methods such as crystallographic texture analysis in comparable objects (e. g. Ratka/Sahm/Bunk 1999; Wirth 2003; Kienlin 2008a; Artioli/Mapelli 2009). Judging from the deformation of oxides and porosity the total reduction in thickness for this group of hammer axes typically remained (well) below 50 % (fig. 3.10 M20). In some cases, however, a (much) stronger deformation was achieved (fig. 3.9). Obviously, the amount of working required was dependent upon the success and care given in the casting process. While limited in comparison, for example, to some Early Bronze Age axes (Kienlin 2008a), this nonetheless reflects considerable effort and a concern on behalf of Eneolithic/Copper Age metalworkers with the finish and appearance of their products.

In sample no. 176 there is some slight deformation of the recrystallised grains at the cutting edge. Somewhat further back, in particular along both surfaces, there still appear some slightly deformed twins. By comparison with experimental data and a larger series of Early Bronze Age axes previously examined, these features point to a reduction in thickness of about 20 % to a maximum of 30 % (fig. 3.10 M16; see appendix I; Northover 1989; 1996; Buchwald/Leisner 1990; Scott 1991; Wang/Ottaway 2004; Kienlin 2008a, 43–75). However, since this deformation did not affect the whole sample area but is clearly restricted to the tip (i. e. the cutting edge) and outward surface of the sample it is unlikely that it represents final cold work planned as a separate production step. Rather it is a side-effect of surface finish by grinding and polishing and/or indicative of some use of limited intensity. The same applies to all other hammer axes examined (fig. 3.13). None of these samples shows deformed grains or strain lines, and what little deformation of twins there is in some of them remains restricted to the surface (figs. 3.9 and 3.10 M13–16). Most likely this superficial deformation is the result of surface finish or use (fig. 3.10 M17). A number of axes without any signs of deformation support this interpretation (e. g. sample nos. 45, 141 and 144). Quite obviously no deliberate cold work was carried out nor was there any attempt at improving mechanical properties by final cold hammering.

Even so, surface finish and/or initial use left their traces in the hardness values and might have added to the durability of these implements. From figure 3.12 it can be seen that the axes with some slightly deformed twins in their outward microstructure tend to have somewhat higher hardness values at the cutting edge (hardness pt. 1) than

Sample no.	HV pt1	HV pt3	Cu	S	Sn	Pb	As	Sb	Ag	Ni	Co	Fe	Bi	Sum TE
Eneolithic/Copper Age hammer axes														
45	59.8	68.1	99.6	-	-	-	0.4	-	-	-	-	-	-	0.4
62	97.6	70.7	100	-	-	-	-	-	-	-	-	-	-	-
82	81.2	97.1	99.7	-	-	-	-	-	-	-	-	0.3	-	0.3
85	76.6	70.2	99.3	-	-	0.4	-	0.3	-	-	-	-	-	0.7
96	74.2	74.2	99.8	-	-	-	-	-	-	-	0.2	-	-	0.2
100	74.2	113.1	99.1	-	0.2	-	0.5	-	-	-	0.2	-	-	0.9
141	72.7	83.2	99.1	-	-	-	-	-	0.4	0.5	-	-	-	0.9
144	65	66.3	99.6	-	-	-	-	0.4	-	-	-	-	-	0.4
153	117.1	78.2	99.5	-	-	-	-	-	0.2	0.1	0.1	0.1	-	0.5
176	99.4	97.6	99.4	-	-	-	0.2	0.4	-	-	-	-	-	0.6
181	97.6	45.6	99.7	-	-	0.3	-	-	-	-	-	-	-	0.3
182	111.9	71.9	99.6	-	-	-	-	-	0.4	-	-	-	-	0.4
183	67.8	74.2	100	-	-	-	-	-	-	-	-	-	-	-
184	63.8	61.8	99.1	-	-	-	-	-	0.4	0.5	-	-	-	0.9
185	83.2	78.2	99.8	-	0.2	-	-	-	-	-	-	-	-	0.2
190	-	-	99.1	-	-	-	-	0.3	0.6	-	-	-	-	0.9
196	74.8	76.3	100	-	-	-	-	-	-	-	-	-	-	-

Fig. 3.12: Hardness and composition of the Eneolithic/Copper Age hammer axes examined for this study (Vickers microhardness HV0.1 at the tip of the sample [pt. 1 = cutting edge] and at the back of the sample [pt. 3 = core]; EDX analyses, weight-%, rounded to one decimal).

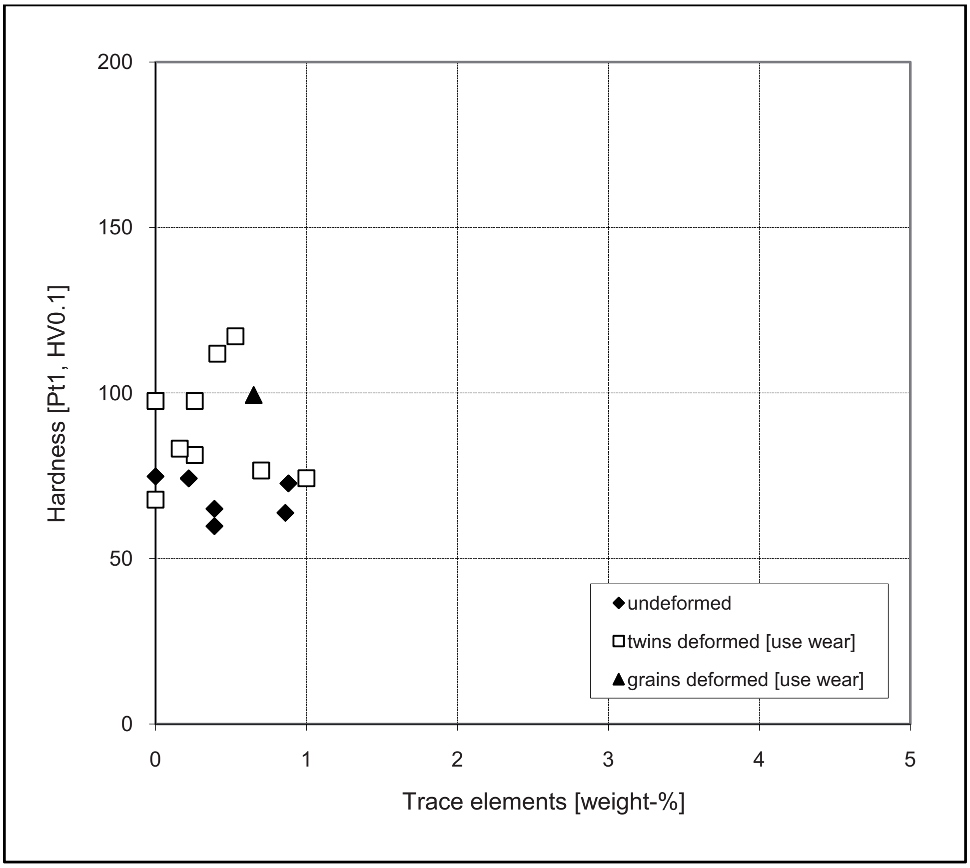


Fig. 3.13: The hardness of the Eneolithic/Copper Age hammer axes, depending on composition and work hardening (surface finish and/or use wear).

those without any deformation and therefore unused and with a method of surface finish which did not affect their microstructure. In sample no. 153, for example, hardness drops from 117.1 HV at the cutting edge to 78.2 HV in the backward part of the sample (hardness pt. 3) for this reason. In sample no. 182 there is a decline from 111.9 HV (pt. 1) to 71.9 HV (pt. 3). The micro-hardness test (HV0.1) that had to be applied to the small samples available is sensitive to small-scale differences in deformation and composition, pores and grain boundaries; hence not every reading fits in. But there is a clear patterning to show that surface finish although maybe not carried out to this end as well as the initial stages of use very likely had a beneficial effect on the subsequent performance of these axes. However, all hardness values observed in this group of samples (fig. 3.13) are systematically higher than might be expected from the rather pure copper used for these axes, be it fully recrystallised (e. g. sample no. 141 with 72.7/83.2 HV [pts. 1/3]) or slightly deformed (e. g. sample nos. 153 and 182 above). We will return to this point in our discussion on oxide inclusions and working of the axes (see chapter 3.5).

3.3 Casting and Working II: The Metallographic Evidence of the Axe-Adzes

In good accordance with the broadly contemporaneous group of hammer axes discussed above, all axe-adzes examined for this study contain copper oxide. This points to the practice and conditions of casting, and their fully recrystallised microstructure gives evidence of a heat treatment during the subsequent production process (figs. 3.14 and 3.15 M2/8; see also the corresponding tables in appendix II). In all samples there is abundant evidence of twinning with twin bands typically visible in most grains throughout the whole sample area (figs. 3.14 and 3.15 M9; among the few exceptions with a somewhat lower density of twins e. g. sample nos. 94 and 98). They give evidence of forging while the object was hot or prior to annealing. This working resulted in a rather dense microstructure, and in most cases there is very little porosity left in the blade and cutting edge area examined (fig. 3.15 M1). Finally, as with the hammer axes previously discussed only few axe-adzes provide unequivocal evidence of cold working in the final step of production (fig. 3.15 M13–16).

Quite obviously both hammer axes and axe-adzes were produced in the same broad tradition of metalworking with minor variation in detail. This finding should not be taken for granted given their wide distribution in space and time as well as the existence of numerous variants indicative of local production (see chapter 3.1). From a wider perspective hardly any of the production steps involved is without alternative. The formation of a distinct metalworking tradition and the stability of technological choices evident

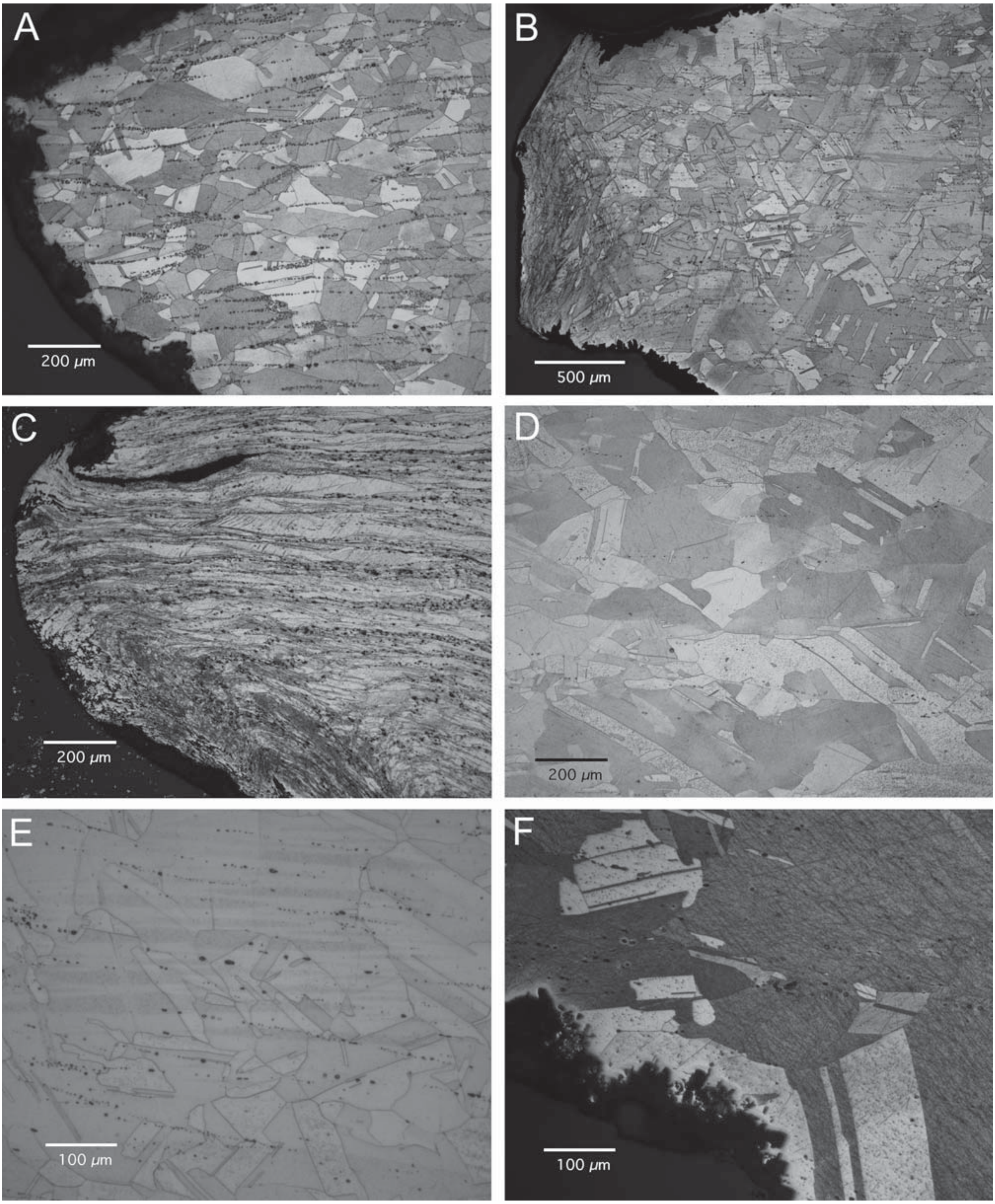


Fig. 3.14: Characteristic microstructures of Eneolithic/Copper Age axe-adzes examined for this study (A: sample no. 178-1; B: sample no. 107-1 [note use wear, left at the tip of the sample]; C: sample no. 177-1 [note the heavily deformed grains; this axe's cold work is the big exception in the group of shaft-hole axes]; D: sample no. 98; E: sample no. 48-2; F: sample no. 175-2).

in both Eneolithic/Copper Age hammer axes and axe-adzes are in need of explanation. Why turn to casting, for example, when there are traditions of working native copper without knowledge or use of casting technique such as in North America (Ehrhardt 2009)? Why turn to hot work or annealing, when the early metalworking of the Iberian Peninsula provides an example of a tradition largely operating on the basis of cold working as-cast objects without knowledge of, or interest in, the beneficial effects of heat treatment well into the Bronze Age (Rovira Llorens/Gómez Ramos 2003, 161 fig. 4.2, 165 fig. 4.5)?

Copper oxide is present in all axe-adzes examined in variable amounts from 0.61 % of sample area in sample no. 48-1 to 3.69 % in sample no. 105-1 (figs. 3.15 M2 and 3.16). The mean value is at 1.7 %, i. e. slightly below that of the contemporaneous hammer axes. There is no equivalent to sample no. 176 with 7.56 % oxides, which underlines its exceptional character among the group of hammer axes discussed above. However, among the axe-adzes as well there are two broad groups indicating varying 'success' or care given to achieving control over gas absorption during melting and casting. A significant number of the axe-adzes more or less clearly remain below an oxide content of 2 %, and there seems to be a tendency for a separate group to cluster in the 2 % to 4 % oxide range (fig. 3.16). As mentioned above, this should not be taken as the result of a more 'primitive' casting technique in the latter group since there is no clear indication what these differences meant to Eneolithic/Copper Age metalworkers. Did they go unnoticed or were individual castings perceived as 'suboptimal' under handling? Or do we in fact observe true differences in attention paid to this detail of the casting process? In any case, subsequent working of the axe-adzes in question was not dependent on oxide content, though we must remember that this group is composed of those that survived in the archaeological record and were not directly remelted. In both oxide 'groups' comparable time and effort were involved in forging (see below). Generally speaking, a much higher oxygen pick-up was acceptable than modern practice suggests, and it did not cause fundamental problems upon casting and subsequent working.

In some of the axe-adzes examined there are somewhat higher trace elements contents, up to around 2 %, than there are in the group of hammer axes sampled (fig. 3.17). With the influence of skill and attention paid during casting on oxygen pick-up and oxide content already mentioned, this allows a look at another variable discussed in this context: namely arsenic, which is thought to have a de-oxidising effect by forming insoluble oxides which are removed upon casting (e. g. Charles 1967, 21; cf. Ottaway 1994, 130; Kienlin 2008a, 255–262). From figure 3.16, however, it is quite likely that there is no such straightforward influence, and trace elements do not necessarily improve casting properties. There is no apparent relation between trace element content and the frequency of oxide inclusions. In sample nos. 118-2, 138-2 and 179, for example, with 3.48 %, 2.65 % and 3.14 % of sample area there are many oxides at comparatively high trace element contents of 1.1 %, 1.2 % and 1.6 % respectively. With almost pure copper on the other hand there are oxide contents varying widely, for example, from 0.61 % in sample no. 48-1 (0.2 % TE) to 2.34 % in sample no. 189 (0.3 % TE). In consequence, it is not composition alone (i. e. the copper chosen) which reduces oxide inclusions but the handling of the molten copper prior to and during casting (e. g. the use of a charcoal layer to cover the crucible). It is in this respect – be it by chance, skill or attention paid – that there is a difference between high and low oxide pieces in both the hammer axe and the axe-adze group.

In his comments on an earlier version of this study P. Bray (Oxford) rightly stressed that figure 3.16 represents the end of the casting and working process and the trace elements that are present need to be discussed separately (Bray pers. comm. 28. 6. 2010). Silver in particular which is present in some of the axes is more noble than copper and would not have a de-oxidising effect. The sum of trace elements was used here to match the corresponding graph on composition and hardness of the axes below (fig. 3.18) and because traces of silver will not affect this study's line of argument since most other elements commonly found in the axes will preferentially oxidise compared to copper. The more important point is the first one: Figure 3.16 shows the static result of the casting process in terms of composition and oxide inclusions. It is quite clear that during melting and casting trace elements were oxidised and their relative affinities to oxygen had an influence on the rate of this process. Hence from a range of different 'starting points' in terms of original composition there was differential oxidation and in this sense trace elements may be said to have a de-oxidising effect and some more so than others. The point is that in the end (fig. 3.16) there is no linear relation of composition and the frequency of oxide inclusions. Irrespective of the total trace element levels, the starting point and the relative amount of trace elements removed during casting the result was highly variable. This implies that handling was a major determining factor for the level of oxide inclusions. It is impossible to determine the original trace element content and the loss during melting and casting. But it is quite clear that using raw copper from across the spectrum of initial compositions could result in either high 'quality' or low 'quality' in terms of oxide inclusions (and porosity) that remained.

Although some pieces have somewhat higher trace element contents in the axe-adzes, too, there are no inhomogeneities left from the as-cast microstructure (figs. 3.14 and 3.15 M6). At some stage after casting a heat treatment (either hot working or annealing; see chapter 3.5) was carried out which not only brought about a complete recrystallisation but also was of sufficent intensity to remove any coring that resulted from rapid cooling and disequilibrium upon solidification. With temperatures required in excess of 500 °C to 600 °C and about half an hour to achieve homogenisation the heat treatment encountered can be described as rather intense (fig. 3.15 M11/12).

Twinning, as pointed out above, may indicate either hot

Sample no.	Porosity, phases and inhomogeneities						Production steps						Final cold work					Total working		
	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20
Eneolithic/Copper Age axe-adzes (type)																				
48-1 (Jászladány)	0	0.61%	a	x	0	0	0	xx	xx	x	xx	xx	0	(x)	0	0%?	x	x	-	~50%?
48-2 (Jászladány)	0	0.75%	a	x	0	0	0	xx	xx	x	xx	xx	0	(x)	0	0%?	x	(xx)	-	>50%
52 (Nógrádmarcal)	0	1.88%	b	0	0	0	0	xx	(xx)	xx?	xx	xx	(x)	x	0	~30%?	x	x	-	~50%
91-1 (Mugeni)	0	0.92%	a	x	0	0	0	xx	xx	x	xx	xx	0	0	0	0%	x	x	-	max. 50%
91-2 (Mugeni)	0	0.86%	a	x	0	0	0	xx	xx	x	xx	xx	0	0	0	0%	x	x	-	<50%
94 (Kladari)	0	2.02%	(a)	x	0	0	0	xx	(xx)	xx?	xx	xx	(x)	(x)	0	20-30%?	x	x	-	<50%
98 (Jászladány)	0	1.16%	(a)	x?	0	0	0	xx	(xx)	x	xx	xx	0	(x)	(x)	0%?	x	x	-	<50%
105-1 (Jászladány)	0	3.69%	a	x	0	0	0	xx	xx	x	xx	xx	0	0	0	0%	0	xx	-	>50%
105-2 (Jászladány)	0	2.54%	a	x	0	0	0	xx	xx	x	xx	xx	0	0	0	0%	(x)?	xx	-	>50%
107-1 (Jászladány)	0	0.96%	a	x	0	0	0	xx	xx	x	xx	xx	x	x	xx	0%?	x	xx	-	>50%
107-2 (Jászladány)	0	1.29%	a	x	0	0	0	xx	xx	x	xx	xx	x	x	xx	0%?	x	(xx)	-	~50%
118-1 (Nógrádmarcal)	x	1.22%	b/a	x	0	0	0	xx	xx	x	xx	xx	0	0	0	0%	x	(x)	-	<<50%
118-2 (Nógrádmarcal)	x	3.48%	b/a	x	0	0	0	xx	xx	x	xx	xx	0	0	0	0%	0	(x)	-	<<50%
138-1 (Jászladány)	0	1.18%	a	x	0	0	0	xx	xx	x	xx	xx	0	0	0	0%	0	x	-	~50%?
138-2 (Jászladány)	0	2.65%	a	x	0	0	0	xx	xx	x	xx	xx	0	0	0	0%	0	x	-	~50%
175-1 (Jászladány)	x	0.91%	a	x	0	0	0	xx	xx	x	xx	xx	0	0	0	0%	0	(x)	-	<<50%
175-2 (Jászladány)	x	1.62%	(a)	x	0	0	0	xx	xx	x	xx	xx	0	0	0	0%	0	(x)	-	<<50%
177-1 (Jászladány)	0	2.13%	a	x	0	0	0	xx	xx	xx	xx	xx	xx	xx	(xx)	45-50%	0	xx	-	>>50%
177-2 (Jászladány)	0	2.62%	a	x	0	0	0	xx	xx	xx	xx	xx	(xx)	xx	(xx)	40-45%	0	xx	-	>50%
178-1 (Jászladány)	0	1.31%	a	x	0	0	0	xx	xx	x	xx	xx	0	0	0	0%	0	x	-	~50%
178-2 (Jászladány)	0	1.38%	a	x	0	0	0	xx	xx	x	xx	xx	0	0	0	0%	0	x	-	~50%?
179 (Jászladány)	(x)	3.14%	(b)	x	0	0	0	xx	xx	x	xx	xx	0	(x)	0	0%?	x	(x)	-	<<50%
180-1 (Kladari)	0	2.52%	a	x	0	0	0	xx	xx	xx	xx	xx	(xx)	xx	(xx)	40-45%	0	xx	-	>50%
180-2 (Kladari)	x	2.2%	a	x	0	0	0	xx	xx	(xx)?	xx	xx	0	x	0	10-20%?	(x)	(x)	-	<50%
189 (Jászladány)	0	2.34%	a	x	0	0	0	xx	(xx)	x	xx	xx	0	(x)	0	0%?	x	(x)	-	<50%
205-1 (Jászladány)	0	0.72%	a	(x)	0	0	0	xx	xx	x	xx	xx	0	(x)	0	0%?	(x)	x	-	~50%?
205-2 (Jászladány)	0	1.43%	a	x	0	0	0	xx	xx	x	xx	xx	0	0	0	0%	0	x	-	~50%?
206-1 (Jászladány)	0	0.72%	a	(x)	0	0	0	xx	xx	x	xx	xx	0	0	0	0%	0	(x)	-	<50%
206-2 (Jászladány)	0	1.04%	a	x	0	0	0	xx	xx	x	xx	xx	0	x	0	0%?	x	(x)	-	<<50%

Fig. 3.15: Microstructural features of the Eneolithic/Copper Age axe-adzes examined for this study. M1: porosity (0 = none/hardly any; x = occasionally; xx = frequent) – M2: oxides (% of sample area) – M3: kind of oxides (a = [Cu+Cu$_2$O]-eutectic; b = particles) – M4: influence of oxides on hardness (0 = none; x = yes/assumed) – M5: further phases (0 = none/hardly any; x = present) – M6: coring in copper matrix (0 = none/hardly any; x = weak residual coring; xx = heavily cored) – M7: casting grains (0 = none; x = present) – M8: recrystallisation (0 = none; x = partial; xx = complete) – M9: twinning (0 = none; x = frequent; xx = in most/all grains of sample area) – M10: production steps after casting (0 = none; x = as-cast, cold worked, or: cold worked, annealed, or: hot worked; xx = cold worked, annealed, cold worked, or: hot worked, final cold work) – M11: homogenisation (0 = none; x = partial; xx = complete) – M12: intensity of annealing/application of heat (0 = equi-axed grains; x: equi-axed grains, partly homogenised; xx: equi-axed grains, homogenised) – M13: deformation of grains (0 = none; x = moderate; xx = heavily deformed) – M14: deformation of twins (0 = none; x = moderate; xx = heavily deformed) – M15: strain lines (0 = none; x = one system; xx = duplex slip) – M16: strength of final cold work (% reduction in thickness, close to the cutting edge/tip of the sample) – M17: wear traces (0 = none; x = additional deformation at the cutting edge due to moderate use; xx = tip of the sample heavily deformed due to heavy use) – M18: deformation/breakage of porosity/oxides (0 = none; x = moderate; xx = heavily deformed) – M19: deformation of coring (0 = none; x = moderate; xx = heavily deformed) – M20: estimated total reduction in thickness (% reduction in thickness, close to the cutting edge/tip of the sample).

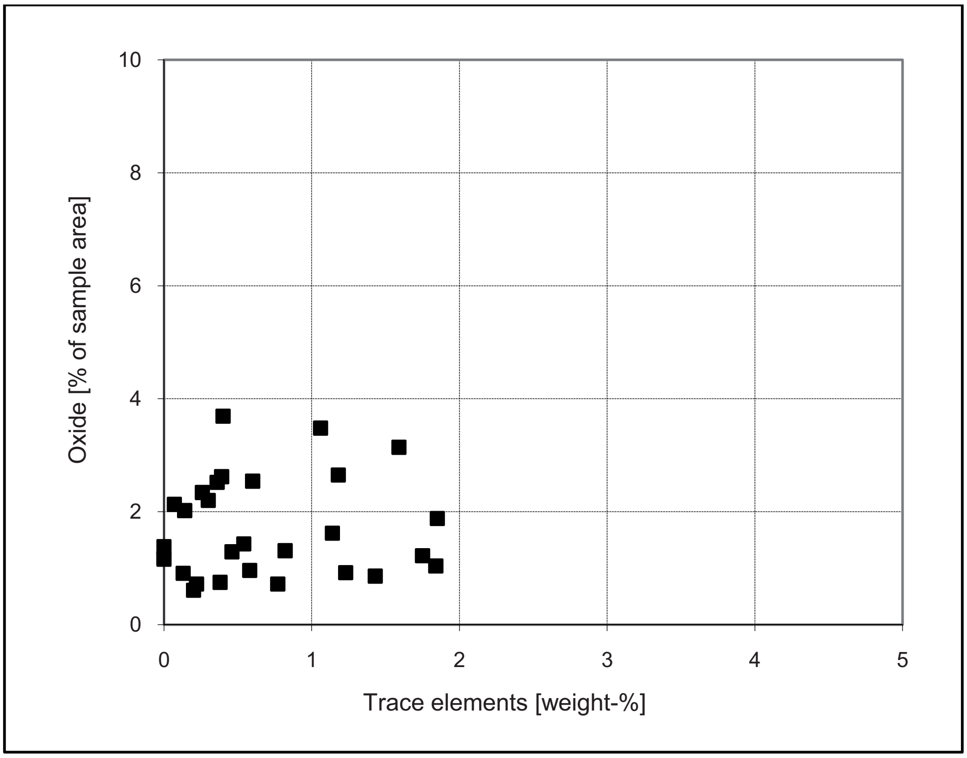


Fig. 3.16: Composition and frequency of oxide inclusions in the Eneolithic/Copper Age axe-adzes examined.

working or cold work followed by annealing; without any clear guidance provided by the microstructure as to which process actually took place. Similarly, twinning cannot be used to directly infer deformation rates. But its presence throughout the whole sample is clear evidence that either by hot work or cold work the production of all the axe-adzes examined involved some forging to give these implements their final shape and surface finish. In this process oxide inclusions sometimes were heavily deformed from their original shape (fig. 3.14), and porosity that remained from the casting process was largely or in part removed (fig. 3.15 M1/18). At least along their cutting edge and blade, that apart from the shaft-hole certainly required and attracted most work to produce a proper weapon or tool, the axes obtained a rather dense microstructure.

Based on deformed oxide inclusions and porosity for a number of samples a total reduction in thickness can be inferred that commonly remained well below 50 % (fig. 3.15 M20; Northover 1989; 1996; Kienlin 2008a, 74–77). Others had received a working in the 50 % range and a smaller number show signs of heavier working above this value (only in one case well above 50 %: sample no. 177-1). With regard to possible uses of these implements it is important to note that there are no systematic differences between the axe arm and the adze arm (fig. 3.15 M20; somewhat more marked differences e. g. in sample nos. 180-1 [classified as > 50 %] and 180-2 [< 50 %]; see also below for different cold work). What differences there are quite obviously correspond to the variation that is to be expected from working done by hand under prehistoric/

Sample no.	*HV pt1*	*HV pt3*	*Cu*	*S*	*Sn*	*Pb*	*As*	*Sb*	*Ag*	*Ni*	*Co*	*Fe*	*Bi*	*Sum TE*
Eneolithic/Copper Age axe-adzes														
48-1	97.6	111.9	99.8	-	-	-	-	-	-	0.2	-	-	-	0.2
48-2	98	88.8	99.6	-	-	-	-	-	0.2	-	0.2	-	-	0.4
52	105.1	89.6	98.1	-	-	-	-	0.7	1.2	-	-	-	-	1.9
91-1	95.4	86.9	98.8	-	-	-	-	0.4	0.5	-	0.3	-	-	1.2
91-2	95.8	86.5	98.6	-	0.5	-	-	0.3	0.4	-	-	0.2	-	1.4
94	99.4	92.8	99.9	-	-	-	-	-	-	-	0.1	-	-	0.1
98	89.6	83.9	100	-	-	-	-	-	-	-	-	-	-	-
105-1	66.8	50.5	99.6	-	-	-	-	-	-	-	0.1	0.3	-	0.4
105-2	78.2	94.5	99.4	-	-	-	-	0.5	-	-	-	0.1	-	0.6
107-1	104.1	74.2	99.4	-	-	-	-	-	0.4	-	-	0.2	-	0.6
107-2	129.1	85	99.5	-	0.3	-	-	-	0.2	-	-	-	-	0.5
118-1	113.6	78.5	98.1	-	-	-	-	0.6	0.6	0.4	0.3	-	-	1.9
118-2	66.8	67.8	98.9	-	-	-	-	0.8	0.3	-	-	-	-	1.1
138-1	94.1	83.2	100	-	-	-	-	-	-	-	-	-	-	-
138-2	106.6	101.2	98.8	-	-	-	0.9	-	-	-	-	0.3	-	1.2
175-1	91.2	95.4	99.9	-	-	-	-	-	-	-	0.1	-	-	0.1
175-2	79.8	84.3	98.9	-	-	-	-	-	0.7	0.2	0.2	-	-	1.1
177-1	114.7	109.2	99.9	0.1	-	-	-	-	-	-	-	-	-	0.1
177-2	108.2	86.9	99.6	-	-	-	-	-	0.4	-	-	-	-	0.4
178-1	92	76.9	99.2	-	0.2	-	-	-	-	0.5	-	0.1	-	0.8
178-2	81.2	69.4	100	-	-	-	-	-	-	-	-	-	-	-
179-1	108.7	95.4	98.4	0.1	0.4	-	0.3	0.8	-	-	-	-	-	1.6
180-1	112.5	101.2	99.6	-	-	-	-	-	0.3	-	0.1	-	-	0.4
180-2	86.9	82.2	99.7	-	-	-	-	0.3	-	-	-	-	-	0.3
189	77.2	62.9	99.7	-	-	-	-	-	0.3	-	-	-	-	0.3
205-1	77.6	70.7	99.2	-	-	-	-	-	0.4	-	-	0.4	-	0.8
205-2	80.5	74.2	99.5	-	-	-	-	0.2	-	-	-	0.1	0.2	0.5
206-1	76.6	74.2	99.8	-	-	0.2	-	-	-	-	-	-	-	0.2
206-2	107.2	94.5	98.1	-	-	-	0.6	0.3	0.4	0.6	-	-	-	1.9

Fig. 3.17: Hardness and composition of the Eneolithic/Copper Age axe-adzes examined for this study (Vickers microhardness HV0.1 at the tip of the sample [pt. 1 = cutting edge] and at the back of the sample [pt. 3 = core]; EDX analyses, weight-%, rounded to one decimal).

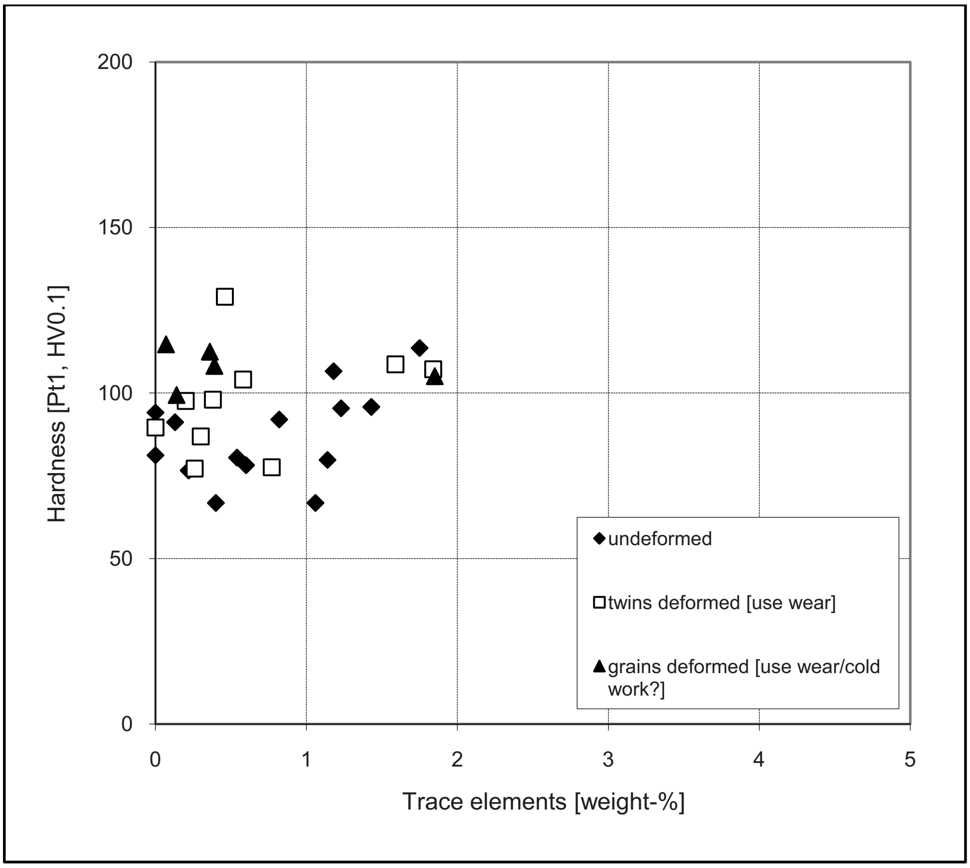


Fig. 3.18: The hardness of the Eneolithic/Copper Age axe-adzes, depending on composition and work hardening (surface finish/use wear) or – in few cases only – possible cold work.

traditional conditions, rather than to any functional considerations concerning axe as opposed to adze function. Similarly, the differences in total reduction in thickness observed between the axes do not indicate a systematic patterning. Rather they seem to reflect differences in the amount of working required depending upon the 'success' and the care given during the casting process. The overall impression is that after casting some of the axes still required considerable effort to remove casting seams or feeders and compensate for surface defects. More generally speaking, the metalworkers involved were very concerned with the finish and surface appearance of their products.

In accordance with the hammer axes discussed before in a majority of the axe-adzes examined there is no clear-cut evidence of final cold work (figs. 3.14, 3.15 M13–16 and 3.18). In fourteen samples there is no sign of cold work at all, and in another ten what little superficial deformation there is clearly has to attributed to surface finish and/or use. Sample nos. 107-1 and 107-2 belong to the latter group and show some deformed grains right at the tip of the sample, which is the cutting edge of the implement. In the other ones grains are undeformed, and slightly deformed twins are restricted to the cutting edge and surface in a way that rules out any deliberate cold work in the sense of hammering or forging. In sample nos. 52 and 94 at the cutting edge there is some more extensive deformation of the recrystallised grains, and slightly deformed twins extend somewhat further back. Hence in figure 3.18 these pieces were classified as possibly indicating some rather light cold work in the 20 % to 30 % deformation range. However, since this deformation is far from affecting the whole sample it should rather be seen as a side-effect of surface finish by grinding and polishing and/or indicative of some use hardening of limited intensity (hence 'grains deformed [use wear/cold work*?*]' in the caption to fig. 3.18). It is only in three samples then (nos. 177-1, 177-2 and 180-1) that on the cutting edge there are heavily deformed grains. With both deformed grains and twins extending backwards there is clear evidence of final cold work in the 40 % to 50 % range, that most likely was conceived of as a separate production step.

The micro-hardness test (HV0.1) used is sensitive to small-scale differences in deformation (forging/use), pores, grain boundaries or grain size and oxide inclusions (see below). Hence, at first sight the hardness readings in this group of axe-adzes are not absolutely consistent as some undeformed samples have a hardness equal to that of samples deformed by use or cold work (fig. 3.18). There is the same tendency, however, that was noted above with regard to contemporaneous hammer axes, for hardness to be systematically higher than might be expected from the microstructure (deformed/undeformed) and composition (pure copper or copper with rather low trace element contents < 2 % and little solid solution

hardening). Furthermore, there are indications that different mechanisms were involved in hardening and contribute to the overall picture in figure 3.18.

Sample no. 138-1, for instance, consists of pure undeformed copper without solid solution hardening or additional hardness induced by cold work or deformation upon use. Still, its hardness is at 94.1 HV (point 1). It is quite clear that this value does not only reflect the hardness of the copper matrix, but is due to the influence of additional microstructural components on the total hardness of this axe (see chapter 3.5 on oxide inclusions and working). In sample no. 107-2, on the other hand, with the highest hardness reading of 129.1 HV in this group of axe-adzes it is quite obvious that hardness at point 1 (= tip of sample) was affected by the localised occurrence of deformed grains at the cutting edge, i. e. deformation during use (see above). In fact some millimeters back at point 3 in a sample area unaffected by use wear hardness declines to 85 HV. This latter value is still too high for pure undeformed copper (see sample no. 138-1 above). It points to the additional influence of oxide inclusions on the hardness of this axe. Finally, in sample no. 180-1 hardness at point 1 is at 112.5 HV, which is in good accordance with the work hardening expected to occur in this rather pure copper at an estimated reduction in thickness by cold work in the 40 % to 45 % range (see experimental data by Lechtman 1996 and examples in Kienlin 2008a, 51–68). In this case at point 3 hardness is still up to 101.2 HV and confirms the above conclusion that (weaker) cold work also affected the backward part of this sample (i. e. larger parts of the whole blade). In addition, it is likely that the rather high oxide content of this sample (2.52 %) further contributes to this hardness reading.

In conclusion, hardness in this group of axe-adzes is the result of up to three factors or processes involved: a) hardness induced by copper oxide inclusions, b) hardness induced by deformation upon initial use (use hardening), and c) in a minority of axes only, hardness provided by an intentional final cold work proper. In any specific sample the precise contribution of each of these to total hardness (in particular oxide hardness and surface finish/use) is difficult to determine. Still, it is possible to identify some basic principles. In most, if not all, of these axes the presence of copper oxide had an effect on the as-cast hardness. In some pieces the oxide contents differ markedly from the axe arm to the adze arm (e. g. sample nos. 118-1 and 118-2 with 1.22 % and 3.48 % respectively or sample nos. 138-1 and 138-2 with 1.18 % and 2.65 %). This points towards the influence various aspects of the handling of the casting process had on this feature (e. g. the position of the feeder, the time taken for the cast, the temperature/superheat of the molten copper). Accordingly, in these cases the influence of oxides on hardness was different in the axe arm and in the adze arm, but this most likely went unnoticed. It did not, in any case, result in systematic differences upon subsequent working (see fig. 3.15 M2, M10, M16 and M20). It is the presence of a specific type of copper oxide, the so-called (Cu+Cu_2O)-eutectic, as such that allowed or required an adaption of the forging process (see discussion in chapter 3.5).

Deliberate cold work conceived of as a separate (final) production step to increase hardness is typically absent in both the adze-axes and the hammer axes examined (see above). The only unequivocal exception among the axe-adzes is the one with sample nos. 177-1 and 177-2, in which case both the axe arm and the adze arm were substantially cold worked. In another case it is only the cutting edge of the adze arm that was cold worked (sample no. 180-1 with a hardness of 112.5 HV). The axe arm did not receive a comparable treatment (sample no. 180-2, correspondingly with a lower hardness of 86.9 HV). This inconsistency casts doubt on the systematic nature of the forging, as far as final cold work is concerned, which this axe was subject to. Despite the additional hardness provided by oxide inclusions and some superficial deformation (probably related to the surface finish through light hammering, grinding and polishing), it is uncertain if these axes were up to prolonged use involved in practical activities such as cutting down trees or even in mining (see discussion in chapter 5.1). Still they were used and since they are rather soft this use left clear traces in the microstructure of a number of the axes examined (fig. 3.15 M17 and appendix II). Most axes that suffered extensive damage were probably re-cast. In any case, the surviving ones only show the initial stages of use. During these activities some superficial deformation occurred, and the additional hardness thereby induced, albeit limited, certainly proved beneficial for subsequent uses. Apart from differences in oxide content (see above), differential hardening upon use may account for differences in hardness between axe arm and adze arm of some pieces that were not deliberately cold worked (e. g. sample nos. 107-1 and 107-2 with 104.1 HV and 129.1 HV or 118-1 and 118-2 with 113.6 HV and 66.8 HV). The function and the meaning of the axes are discussed in greater detail below in chapter 5.1. It should be noted that there is evidence of some kind of practical activities carried out, but these not necessarily matched our modern uses of (steel) axes. Prolonged use, for example, on wood certainly would have required frequent re-sharpening.

3.4 Eneolithic/Copper Age Casting Technique: Cores and Open Moulds?

Due to the lack of actual mould finds for hammer axes and axe-adzes of the south-eastern European Eneolithic/Copper Age quite different casting methods and moulding materials have been suggested. For an older review of this discussion the reader is referred to the PBF-volume by E. F. Mayer (1977, 12–17). Most recently N. Boroffka (2009a) provided an update on this, and J. Heeb (2009) reported on some preliminary experimental work on the casting of Jászladány type axe-adzes. In the absence of evidence basically all traditional casting methods known have been suggested: one-piece open moulds, closed two-piece moulds as well as lost wax moulding (*cire perdue*). Correspondingly, opinions differ on how the shaft-hole was inserted, and the object was finished (fig. 3.19). Did this distinctive feature

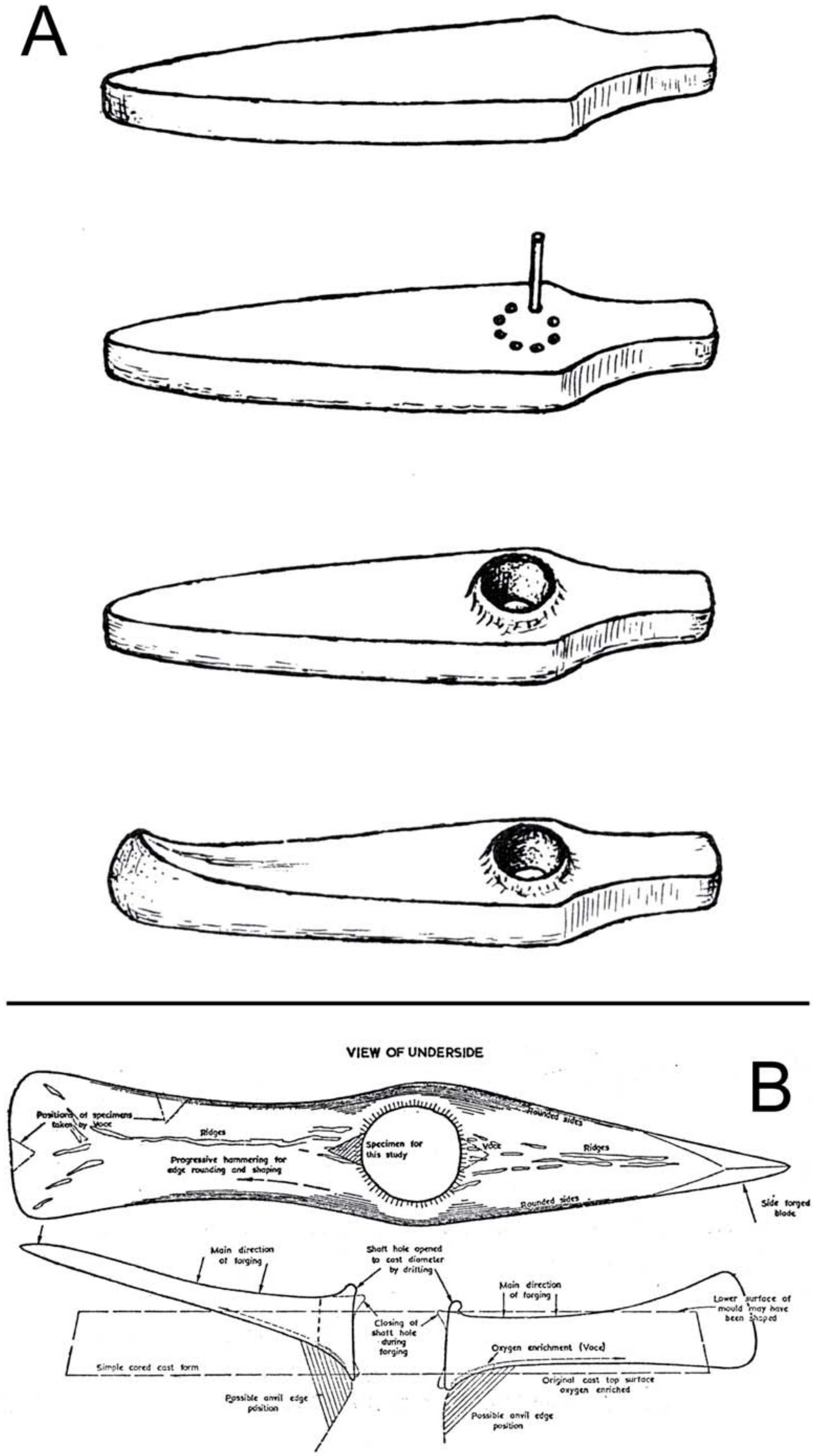


Fig. 3.19: A: Suggested method to insert the shaft-hole by drilling (after Coghlan 1961, 69 fig. 14); B: Suggested approach to forging a shaft-hole axe that was cast in an open cored mould (Charles 1969, 40 fig. 13).

involve the application of lithic technology to a roughly cast or hammered blank, such as drilling and punching out the core? Was it – somewhere in between traditions – punched through the still liquid or red-hot blank cast in an open mould? Or did it involve the fully 'metalworking' approach of inserting a core into an open or closed mould (see, for example, Pittioni 1957, 25–27; Coghlan 1961, 57–58, 69–75; Patay et al. 1963, 47–56; Renfrew 1969, 31; Charles 1969, 40–42; Vulpe 1975, 18; Patay 1984, 13–14; Chernykh 1992, 38–41; cf. Ottaway 2001; Mareş 2002; Kienlin 2008b; 2009; Kienlin/Pernicka 2009)?

Stone moulds are considered possible, but this confronts us with their enigmatic absence from the archaeological record, at least during this early stage of Eneolithic/Copper Age metallurgy (for later Bronze Age examples – in stone, clay and bronze – see for example Drescher 1957; Wyss 1967; 1971; Coghlan 1975; Weidmann 1981; 1982; Tylecote 1987; Ottaway 1994; Armbruster 2000; Wirth 2003; Hänsel/Medović 2004; Jantzen 2008; Primas 2008, 128–131). Alternatively both clay and, less often, sand moulds have been suggested. Sand moulds, in particular, leave little archaeological traces, but experimental work strongly suggests this method needs to be taken into consideration (e. g. Goldmann 1981; 1985; Ottaway/Seibel 1998; Wang/Ottaway 2004; see also Müller-Karpe 1990; Moorey 1994). Transitions between clay and sand based moulding materials may be more floating than such discussions suggest. Sand may be required to temper clay in order improve gas absorption and adjust thermal expansion, while clay may be a necessary additive to sand in order to improve adhesion and prevent 'sand' moulds from crumbling away too readily (Fasnacht 1995a; 1995b).

Further working by cold hammering and annealing or hot working was accepted by early research on the basis of metallographic data (e. g. Renfrew 1969, 31; Mayer 1977, 12–14; Patay 1984, 12–13). However, evidence of the casting method used is at best circumstantial, and the conflicting arguments point to the limitations of surface evidence in response to this question. A lack of casting seams, for example, is taken to imply *cire perdue* (i. e. closed one-piece clay moulds), but problems with the identification of casting seams as opposed to both shrinkage and corrosion are evident (Mayer 1977, 13). It is unclear if past researchers were able to distinguish remains of an as-cast surface from a heavily corroded but worked one. Similarly, often it is unclear whether it was possible to tell the occasional remains of shrinkage in general from casting seams. Above all, most axes received substantial working in terms of shaping and/or surface finish (see chapters 3.2 and 3.3; see also the frequent axe 'marks' found on these implements: Patay 1984), and it is unlikely, therefore, that the surface impression is much help in identifying the casting method applied.

Much the same is true, unfortunately, for the small corpus of metallographic data hitherto available. Often, samples are too small to provide a complete characterisation of the axes and their production processes. This limitation also applies to the present samples, still they are invaluable for commenting on previous suggestions about casting method. First, it is possible that there was some variability in casting technique (Heeb 2009, 416–417), though not to the extent that it caused a clear impression on the oxide data available, both with regard to the type and the amount of oxide inclusions present (see chapters 3.2 and 3.3). Handling of those aspects of the casting process that affect oxygen pick-up and oxide formation was fairly well controlled. This does not, of course, imply standardisation in a modern sense. Obviously, there were varying degrees of 'success' depending on skill involved or just on care given in a specific casting process. Generally speaking, it was possible to cast close to the final shape required. But, again, depending on skill and/or attentiveness some of the axes still required considerable effort to compensate for surface defects that remained after casting. The obvious concern of metalworkers with the finish and surface appearance most likely also affected the size and the shape of their products. Variability of form should not, for this reason, be interpreted in terms of casting technique, for example to rule out the repeated use of moulds from some more durable material such as stone or clay (e. g. Vulpe 1975, 33). The other way round, however, the same is true; evidence of forging be it cold work or hot work does not rule out the use of a casting method that we suspect would render such working unnecessary. We are talking about prehistoric/traditional handicraft here, not modern processes optimised in terms of stable outcome and work expended.

In a classic paper it was shown that the shaft-hole of Eneolithic/Copper Age implements were cast around a core, and the earlier hypothesis that this feature was produced by drilling was discarded (Renfrew 1969, 31; see also Coghlan 1961; Patay et al. 1963). Metallographic data was used to demonstrate that intense forging was involved to bring these artefacts into their final shapes, and the same type of eutectic copper oxide was documented that was found in the present study in many more artefacts of this kind (Renfrew 1969, plates VI and VII; Charles 1969). However, we would argue that it is unlikely that shaping was done by cold work followed by annealing and surface finishing as suggested by Charles (1969, 42). There is no practical reason to transform the object into a soft condition just to finish the surface in the final step, and there certainly is no evidence for "further [i. e. final] cold work on an anvil" (Charles 1969, 42) in the present samples (see chapters 3.2 and 3.3). We will return to the problem of hot work versus cold work below, but before that let us dwell on the question what kind of mould was used, and what role forging had in the shaping of these artefacts.

Charles (1969) suggested that a rough shape, basically a rectangular bloc or blank, was produced in an open cored mould and much deformation was required to achieve the final form. In particular both the axe arm and the adze arm had to be broadened and receive their characteristic bending. A concentration of oxides at the upper surface (in the casting mould), which presumably was left uncovered during casting, certainly is a strong argument in favour

of this view (Renfrew 1969, 31; Charles 1969, 40–42). Although there was variation, and this feature reportedly was less marked in the axe-adze examined (Charles 1969, 41). Given that after casting the complete upper side of the axe should have been flat, most likely rather porous and covered by an oxide layer, one would expect that the necessary working affected the cutting edge of the adze arm rather strongly, although possibly less so than closer to the shaft-hole. Clearly, larger samples penetrating further towards the axes' body would be desirable to support this view, but in the present samples there is no clustering of oxide inclusions along the surface (see chapter 3.3 and the corresponding tables in appendix II). It is unlikely that the oxides in their observed form and distribution are consistent with open mould casting (Kienlin/Pernicka 2009). Forging of the adze arm's cutting edge is not systematically different from that of the axe arm. While there are some samples, in which the oxides are quite heavily deformed into parallel layers, this is not the case in all the axes examined (figs. 3.14 and 3.15). This amount of deformation certainly would not have been sufficient, if the surface was initially flat. The same observation can be made on Eneolithic/Copper Age flat axes that were previously supposed to have been cast in open moulds (see chapter 4.4; Kienlin/Bischoff/Opielka 2006; Kienlin 2008b).

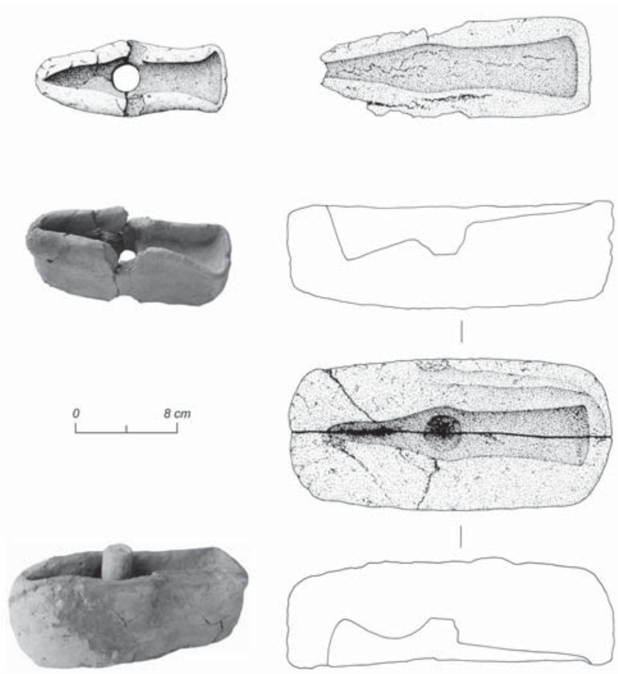


Fig. 3.20: Open cored clay moulds for the casting of shaft-hole axes from Iran and Uzbekistan (after Boroffka 2009, 253 fig. 6).

Recently, N. Borrofka (2009, 254) convincingly argued that outside Europe, where similar axes have a wide distribution from the Aegean to the Indus valley, there is occasional evidence of casting such implements in open one-piece clay moulds, and cylindrical clay cores were used in these rather simple moulds (fig. 3.20). Similarly, J. Heeb (2009, 417) was able to demonstrate experimentally that in an open mould punching the shaft-hole through the still liquid copper by use of a wooden stick is indeed possible. Still, this is no evidence of an exclusively used casting technique, and more complex (sand/clay) moulds may still come to light (*contra* Boroffka 2009). Nor does any approach viable in experiment automatically reflect a part or even the totality of prehistoric practices (*contra* Heeb 2009). All of this does not invalidate the evidence of axes with a low total reduction in thickness (see above). Most likely, E. F. Mayer (1977, 13) hit the point long ago, when he observed that the heavily bent longitudinal section of some axes renders open moulds and forging to achieve their final shape extremely unlikely.

Renfrew (1969) argued for an autonomous development of metallurgy during the south-eastern European Eneolithic/Copper Age. He certainly cannot be accused of taking a 'primitivist' stance of underestimating the inventiveness of European metalworkers. Still, there is an evolutionary undertone to his, as well as to much subsequent, discussion (e. g. Renfrew 1969, 31). It may be due to this particular perspective that some kind of closed (two-piece) mould is not generally taken into consideration. Given that cores were known to produce the shaft-hole (Charles 1969) one might ask instead why large parts of the surface should have remained uncovered, and – more importantly – why both arms should have been cast in one plane? At the risk of applying modern concepts, this approach would have unnecessarily multiplied the amount of work required to prepare the as-cast object for use, especially the massive deformation to bend the arms into their final position. Furthermore, according to Charles (1969, 42) "solidification would not proceed until the mould had been filled and the fire had died down or had been dispersed". In the light of experimental work the opposite is likely. In contact with air, the temperature drops fast, solidification is rapid and gas absorption is high. The problem would be to obtain a complete filling of the mould, especially when the copper is allowed to run into it from an above fire as Charles suggested. The latter proposal is quite inconceivable, but any attempt at casting (from a crucible) into an open mould of this size would result in problems to get the mould completely filled. Not only would the concentration of oxide inclusions increase but also the porosity caused by either water vapour or hydrogen. The microstructures of the axes examined clearly show that this was not the case. By contrast, any kind of cover would allow for solidification to take place more slowly and improve the filling of the mould. With only a little imagination this approach would suggest the addition of important features to the mould. It has been shown above that finishing an axe after casting involved intense working of the cutting edge and blade, but quite clearly their producers did not have to rely on extremely heavy forging to give an axe's arms their final shape.

For the time being all evidence that is available points towards the use of some kind of closed moulds in the production of shaft-hole axes. We should bear in mind, that such Early to Middle Eneolithic/Copper Age implements by no means represent the beginnings of metallurgy in the

area in question. The situation might still seem ambiguous for this group of implements itself, but just somewhat later the shrinkhole in the neck of an Altheim type axe provides unequivocal evidence of closed moulds as casting took place in an upright standing position (see chapter 4.4). Given that at this stage – after the end of the Middle Eneolithic/Copper Age – the interest in massive shaft-hole tools was in decline, one may ask why this innovation should occur in the context of the ongoing production of rather simple forms such as flat axes.

3.5 Casting Process and Oxide Inclusions: Their Influence on Working and Performance

In general terms one would expect the production of copper-based weapons or tools such as the Eneolithic/Copper Age axes in question to involve the following steps: casting – cold working the as-cast object – annealing – final cold hammering (fig. 3.21, from *a* via *b* and *e* to the final microstructure *f*; Northover 1989; Schumann 1991; Scott 1991; Kienlin 2008a, 43–75, appendix I). This procedure has a twofold aim. Irrespective of the casting method applied (open mould casting vs. closed two-piece moulds; see chapter 3.4) some degree of deformation is required to finish the as-cast object. A smooth surface has to be achieved and feeders or casting seams may need to be removed, which is done by hammering and subsequent grinding and polishing. If a stronger deformation is required, such as for shaping an axe's body or blade, this may necessitate more than one annealing process. Final cold work, on the other hand, increases hardness and adds to the strength and durability of a weapon or tool.

The practice of annealing can be traced back to the working of native copper during the Neolithic of the Near and Middle East (see chapter 2.2; e. g. Pernicka 1990, 28–42; Schoop 1995, 35–37; Yalçin 2000; 2003). It implies knowledge of work hardening and the reverse effect of increased temperatures on mechanical properties to restore deformability. Eneolithic flat axes of the Altheim and Vinča types etc., which have a widespread distribution in south-eastern and central Europe somewhat later than the hammer axes and axe-adzes under discussion, clearly follow this procedure. They were cold worked in the as-cast state, followed by annealing and final cold hammering (see chapter 4.3; Budd 1991a; Kienlin/Bischoff/Opielka 2006; Kienlin 2008b; 2009). The tradition thus established can be traced right up to the Early Bronze Age, when a two-step working of flanged axes is the rule. Profiting from the new *fahlore* type copper and tin bronze, a considerable increase in hardness was then achieved by a rather strong final cold work (see chapter 7; Kienlin 2008a).

While this approach is well in accordance with the material properties and the requirements of shaping metal artefacts, there are in fact few steps in the *chaîne opératoire* of early metalworking that necessarily match modern expectations and knowledge on how to proceed 'best'. Hence, despite the early evidence of its use and its long-standing tradition, the knowledge and/or the practice of this process cannot be taken for granted. Instead, we are confronted with technological choices taken by metalworkers operating within a specific technological and cultural tradition. The early metalworking of the Iberian Peninsula was already mentioned as an example of a tradition which did not make regular use of a heat treatment but relied upon cold working as-cast objects (fig. 3.22; Rovira Llorens/Gómez Ramos 2003, 161–165). Now, the hammer axes and axe-adzes of the south-eastern European Copper Age provide another example of such a historically specific trajectory since their microstructures show some distinct deviations from both the previous working of (native) copper and all subsequent (Late) Eneolithic/Copper Age and Bronze Age practice.

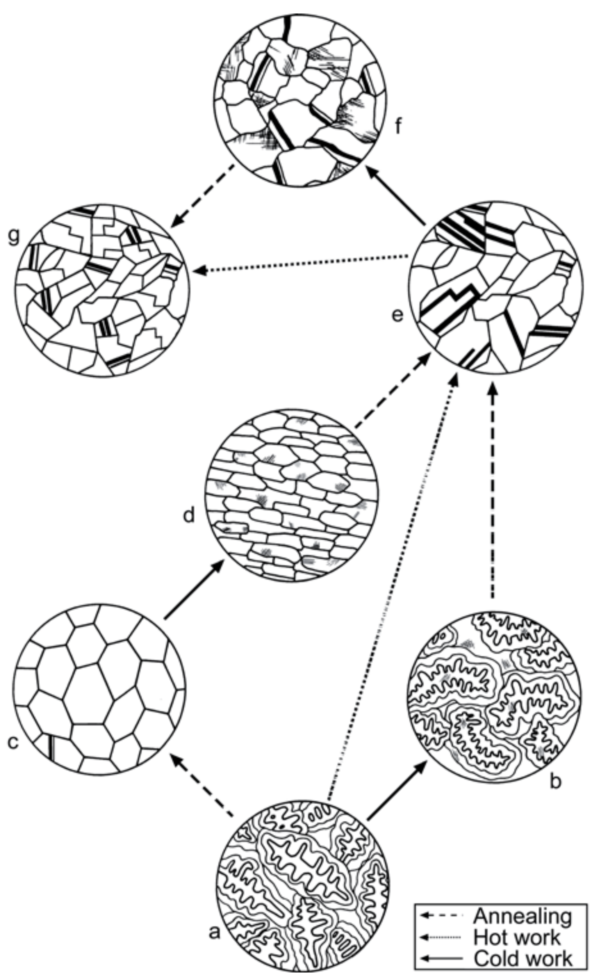
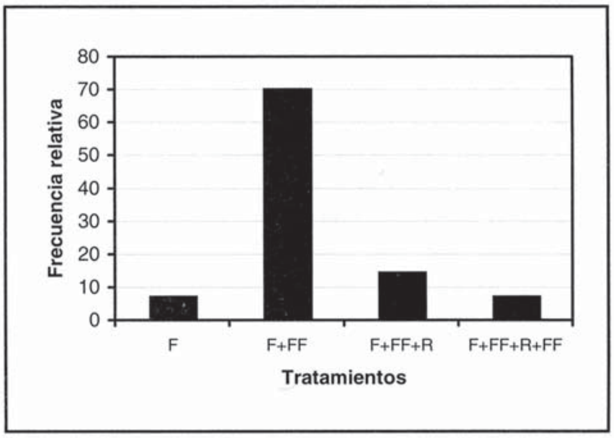


Fig. 3.21: The effect of working on the microstructure of copper (after Scott 1991, 7–8 figs. 11–12). The 'standard' procedure expected in prehistory would start from the dendritic as-cast microstructure a and proceed via b (as-cast, cold worked) and e (annealed/recrystallised) to the final microstructure f (recrystallised, cold worked with strain lines and deformed annealing twins); hot work proceeds from the as-cast microstructure a directly to the final microstructure e (recrystallised with twinning). Microstructure g indicates the decline of grain size that may occur after several cycles of heavy cold work or intense hot work to a high reduction in thickness. From a via c (annealing without prior deformation) and d (cold worked) indicates the modern approach first to achieve a homogenisation before starting to forge an object.



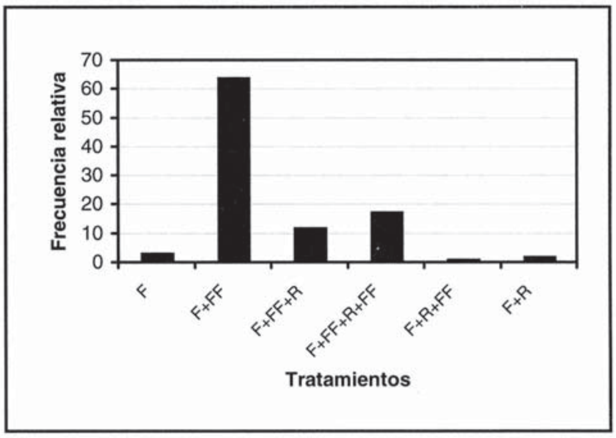


Fig. 3.22: Technological choice and different chaînes opératoires in early copper working – the predominance of cold worked as-cast microstructures during the Eneolithic/Copper Age (above) and Early Bronze Age (below) of the Iberian peninsula (F: as-cast; FF: cold worked; R: recrystallised/ annealed; after Rovira Llorens/Gómez Ramos 2003, 161 fig. 4.2, 165 fig. 4.5)

With only one clear exception, sample no. 177-1/2, the vast majority of both the hammer axes and axe-adzes examined show a fully recrystallised microstructure without any traces of deliberate cold working in the final step (see chapters 3.2 and 3.3). What little deformation there is in the microstructures, such as some slightly deformed annealing twins close to the surface, is indicative of other production steps, namely surface finish or use hardening. Deformed oxide inclusions and porosity as well as numerous annealing twins, on the other hand, clearly show that a forging of some intensity took place to finish the as-cast object. This may have been done by either hot working, or cold work whose effects on the microstructure were erased in a final step of annealing. Thus, in line with younger material from central and south-eastern Europe (Altheim and Vinča etc.; see below) but unlike the example of the Iberian Peninsula the working of the axes in question involved the application of heat. Unlike the younger Altheim and Vinča axes etc., however, as well as later Bronze Age practices no attempt was made to improve their mechanical properties by cold working.

Work hardening of relatively pure copper is limited when compared to high-percent arsenical copper or tin bronze. Yet even an increase in hardness to about 100 HV to 150 HV, that can be achieved at a reduction in thickness of 40 % to 50 % without causing intolerable brittleness, may clearly add to the durability of such implements (Buchwald/Leisner 1990, 73 fig. 20; Northover 1989, 113–114 figs. 13.3, 13.4 and 13.5; Budd/Ottaway 1991, 140 figs. 4 and 5; Lechtman 1996, 488, 494–496 figs. 18, 19 and 20; Junk 2003, 156 fig. 7.26; see also Kienlin/Ottaway 1998; Kienlin 2008a, 263–264 figs. 54 and 55). Given that the application of heat shows an awareness of the alternative, i. e. work hardening, and a conscious decision was taken to avoid (potentially through hot work) or reverse (through a final annealing step) this effect, one may ask, therefore, why the Eneolithic/ Copper Age metalworkers should have chosen to reduce the hardness of the weapons or tools they were producing in this way. Clearly, this carries the risk of applying modern concepts of 'rationality' to prehistoric technology. But it is important to pursue this question precisely because for the remainder of the (Late) Eneolithic/Copper Age and the (Early) Bronze Age metalworkers clearly followed a broadly 'functional' approach, in many ways comparable to modern practice and understanding of metal. The answer we are looking for is closely linked to the problem of whether 'hot work' or 'cold work then annealing' was involved in the production of these axes, and to the influence oxide inclusions had on this decision.

With regard to temperatures required for recrystallisation, duration and practicability, one obviously would expect that forging was done by cold work with intermittent annealing instead of hot working. The microstructures, unfortunately, do not provide unequivocal evidence since both processes will leave behind the same equiaxed grains with extensive twinning. Still, there is at least indirect evidence that forging of the hammer axes and axe-adzes was carried out at high temperatures. Despite generally low impurity concentrations, the axes in both groups after casting had a slightly cored microstructure (see discussion in chapters 3.2 and 3.3). There is evidence of residual coring at least in one hammer axe as well as in some contemporaneous flat axes (see chapter 4.2), and coring is the rule in younger Altheim type flat axes with similarly low impurity contents (see chapter 4.3). In the latter case, while strong enough to allow complete recrystallisation heating was of limited overall intensity. Most likely it was perceived (and practiced) as a separate production step designed to restore deformability while avoiding excessively lengthy annealing times or extreme temperatures, that may cause a deterioration of mechanical properties and increase the amount of fuel needed (Kienlin/Bischoff/Opielka 2006; Kienlin 2008b; 2009).

By contrast, in order to remove coring in the majority of hammer axes and axe-adzes, prolonged heating and high temperatures were required. The procedure encountered is best interpreted as an intense 'warm hammering' or hot work with continuous re-heating during a forging process of some duration (fig. 3.23; see also fig. 3.21, from the as-cast microstructure *a* directly to the final

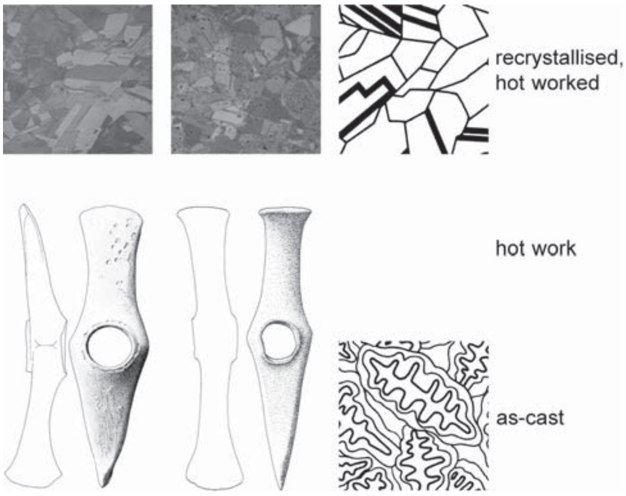


Fig. 3.23: Suggested chaîne opératoire for the finishing of Eneolithic/Copper Age hammer axes and axe-adzes by hot working.

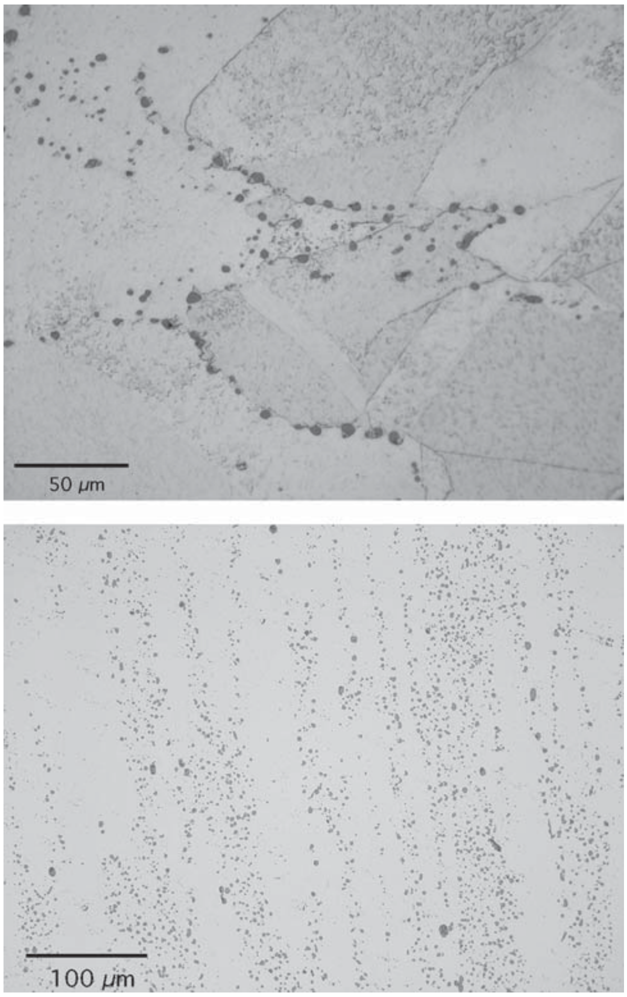


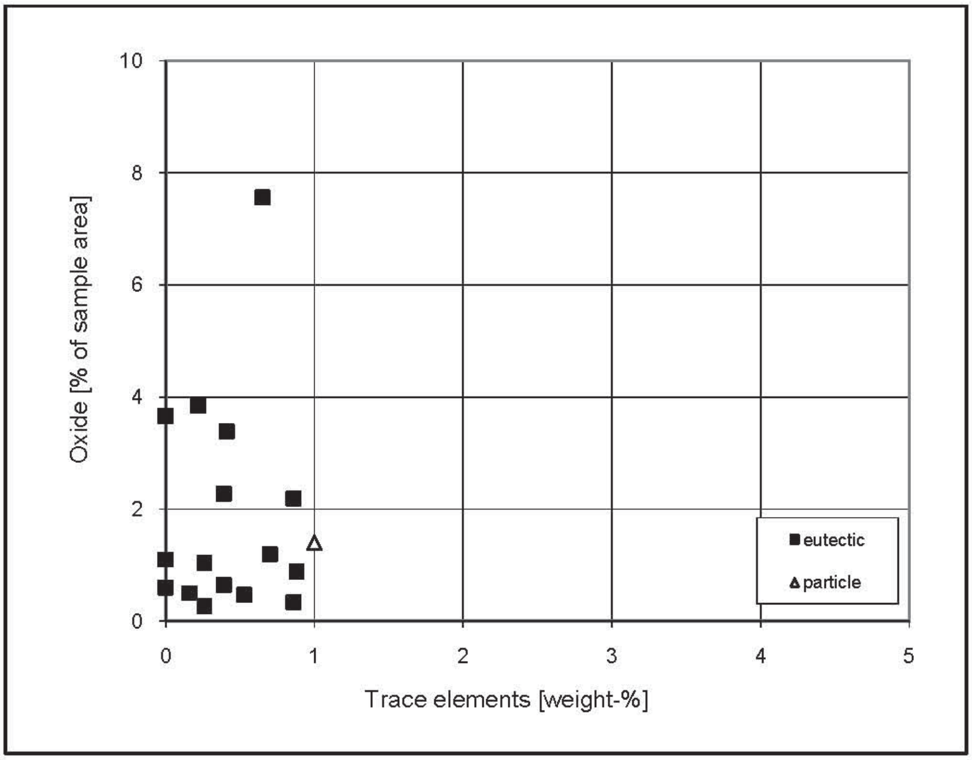
Fig. 3.24: Two examples of the (Cu+Cu$_2$O)-eutectic in Eneolithic/Copper Age hammer axes (above, sample no. 196) and axe-adzes (below, sample no. 105-1).

microstructure *e* or alternatively to *g* with a decline of the grain size due to intense deformation upon continued hot work). The deformation required to finish these axes was achieved while they were heated up with little or no further deformation upon cooling (Kienlin/Pernicka 2009; cf. Ryndina/Ravich 2000; 2001). In practical terms this might be indistinguishable from hammering and intensive annealing at short intervals. For sure our concepts of 'recrystallisation' only as opposed to an additional homogenisation were unknown to prehistoric metalworkers (Budd 1991b). But there remains an emphasis on high temperatures and prolonged heating, as well as an almost complete lack of final cold work clearly recognisable as a separate production step,[6] that are not seen anymore in samples taken from younger axes. It is likely that this difference is a result of changes in casting technique and the influence of oxide inclusions on the subsequent production steps and the performance of the axes (see below).

With just one exception among the hammer axes (sample no. 100) and three more such pieces among the axe-adzes (sample nos. 52, 118-1/2 and 179; figs. 3.10 M3 and 3.15 M3), in all remaining axes of both groups oxides take the form of a network consisting of the (Cu+Cu$_2$O)-eutectic (Schumann 1991, 627–629), which upon forging was deformed more or less heavily (figs. 3.24 and 3.25; see also Coghlan 1961; Patay et al. 1963, 47–56). In the as-cast microstructure this oxide network covered the boundaries of the original casting grains. Upon recrystallisation the oxide layers inhibited the formation of new grains. This is why they are frequently observed along grain boundaries even after annealing. They may also be found, however, incorporated into newly formed grains of the recrystallised microstructure. The same type of eutectic oxide inclusions is predominant among contemporaneous Eneolithic/Copper Age flat axes (see chapter 4.2; Kienlin 2008b; 2009). Younger flat axes, in contrast, rarely show this feature (see chapter 4.3). Instead, most of them contain distinct particles consisting of copper oxide and copper-arsenic oxide that are rarely found in the hammer axes and axe-adzes under discussion here. Thus, without being restricted to either horizon both oxide types show a clear correlation with older and younger Eneolithic/Copper Age axes respectively (for discussion see also chapters 4.5 and 4.6 below).

The hardness of pure undeformed copper is about 50 HV, and solid solution hardening up to about 2 % arsenic is minimal (Buchwald/Leisner 1990; Northover 1989; Budd/Ottaway 1991; Lechtman 1996; Junk 2003; Kienlin 2008a, 263–264 figs. 54 and 55). By comparison the axes with the (Cu+Cu$_2$O)-eutectic oxide type – recrystallised and without final cold work – are harder, sometimes considerably so (fig. 3.26). These discrepancies in hardness values were already noted above (see chapters 3.2 and 3.3). It is the presence of this kind of oxide inclusions, which are hard and brittle, that increases the total hardness of the axes

6 It is in this sense that through the rest of this study the term 'hot work' is applied to axes of this horizon; not to imply a modern high-temperature process or to build up a binary opposition to cold work, but to denote a heat dominated forging process without further deformation upon or after cooling.



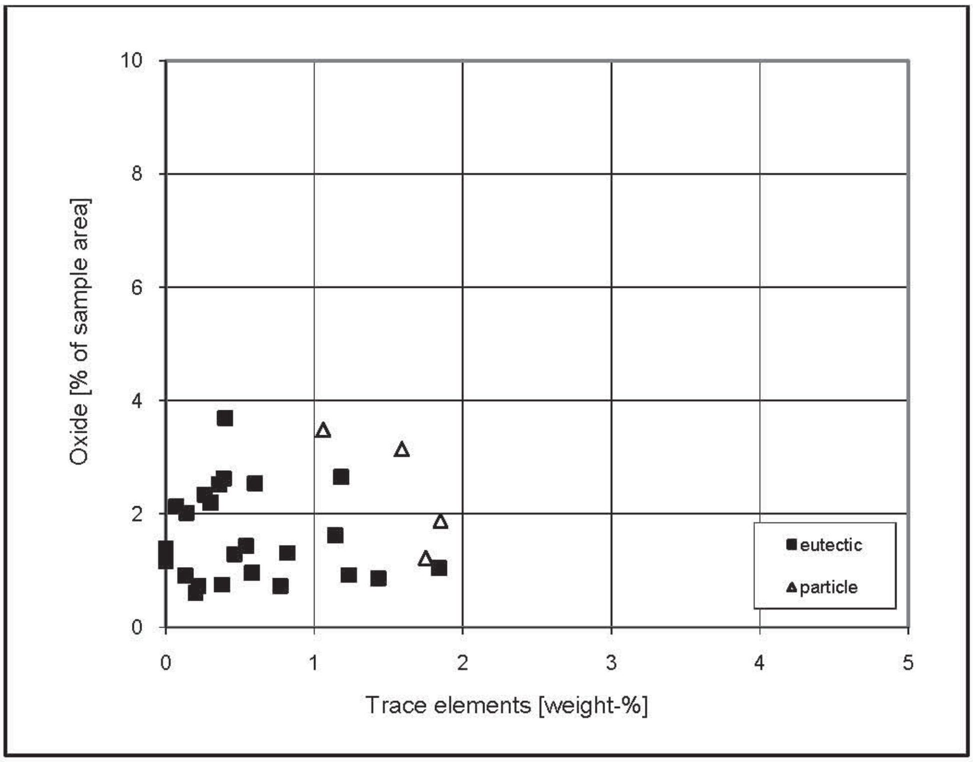


Fig. 3.25A: Frequency and type of oxide inclusions in the Eneolithic/Copper Age hammer axes (above) and axe-adzes (below), depending on composition.

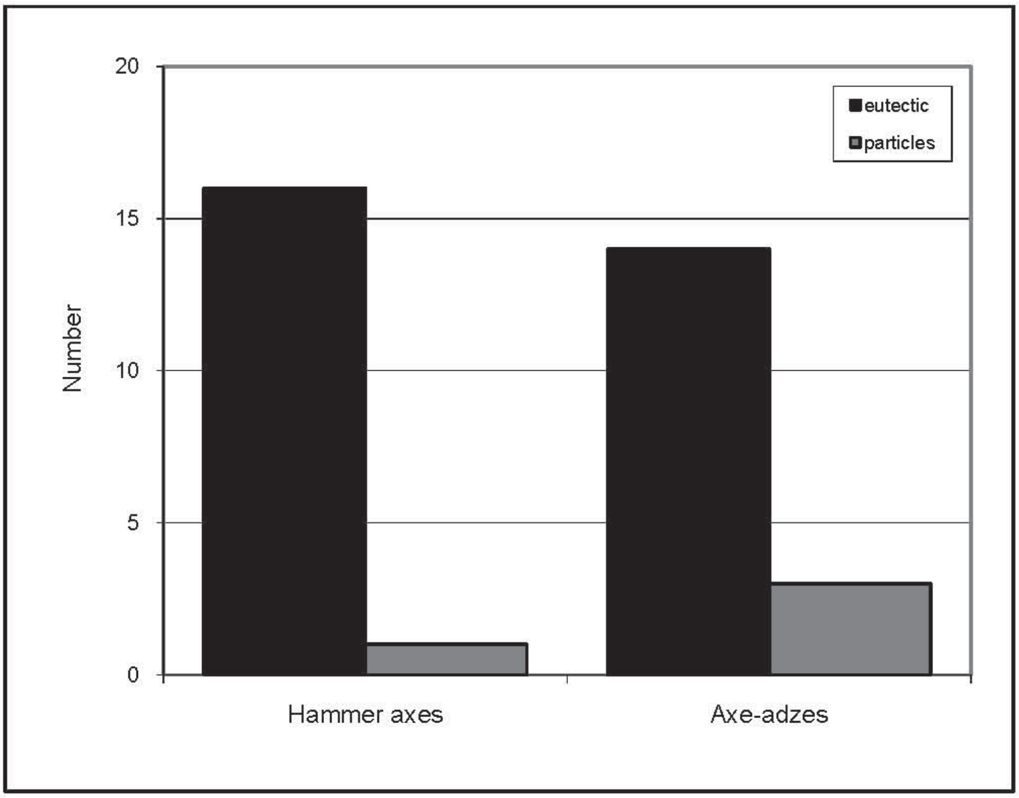


Fig. 3.25B: Comparison of the frequency of different types of oxide inclusions in the Eneolithic/Copper Age hammer axes and axe-adzes (note: here the number of axe-adzes sampled is given, not the number of samples – typically two from each axe-adze –, hence the smaller total number in this group than in fig. 3.25A which shows all the samples).

to values well above what can be expected from their microstructures with little or no signs of final cold work. This brings us back to the question of hot working versus cold working and annealing, and why no attempt was made to benefit from work hardening. Was it that hot working/forging was conceptually linked to *shaping* metal, and this tradition prevented translating knowledge of work hardening, which in principle was available, into a higher 'quality' of axe blades? Was hardness – despite use of some of these axes (see chapter 5.1) – of less importance than we tend to expect? Did the presence of copper oxides provide an alternative mechanism to improve performance by – unconsciously – benefitting from 'shortcomings' in casting technique? Or was it the other way round that the ($Cu+Cu_2O$)-eutectic required hot working, prevented cold work and set a limit to hardness achievable?

It is supposed that the presence of the ($Cu+Cu_2O$)-eutectic along grain boundaries makes the metal brittle while particles of mixed copper-arsenic oxides may be plastically deformed (Northover 1989, 112). The latter is certainly true as there are many younger axes with this feature (see chapter 4.3). Less clear is the effect of the ($Cu+Cu_2O$)-eutectic on workability. There are two different aspects involved, the first of which is illustrated by the copper-oxygen phase diagram: Cu_2O is formed in the molten copper at temperatures above 1000 °C. In equilibrium it is stable down to 375 °C when it is transformed into CuO. In modern as well as in prehistoric practice, however, this transformation won't occur, and the ($Cu+Cu_2O$)-eutectic is present down to room temperature (Schumann 1991, 627–629). To put it the other way round: Upon heating to temperatures up to 1000 °C no changes will occur in the ($Cu+Cu_2O$)-eutectic that might affect deformability and favour hot working. On the other hand, deformation at low temperatures requires the movement of 'defects' through the crystal matrix (Schumann 1991, 386–395; Kienlin 2008a, appendix I). This is made more difficult by the presence of oxide inclusions. Hot working with the continuous formation of new grains avoids this problem.

In modern practice the ($Cu+Cu_2O$)-eutectic is thought to deteriorate mechanical properties, and it is recommended to restrict oxygen pick-up upon casting to prevent its formation. However, in principle both hot and cold working copper containing the ($Cu+Cu_2O$)-eutectic is possible (Schumann 1991, 628). This certainly applies to the forging of our prehistoric axes as well. Overall reduction in thickness is limited, and it is likely that a rather high amount of the ($Cu+Cu_2O$)-eutectic was tolerable without causing problems. Some of the hammer axes and axe-adzes show a high reduction in thickness with the oxides heavily deformed into parallel layers. This indicates that the ($Cu+Cu_2O$)-eutectic did not cause intolerable brittleness. Some kind of working was possible, and there is evidence that either hot working or cold working could be practiced. 'Hot working', as defined above, is the rule in the hammer axes and axe-adzes discussed in this chapter, but among the

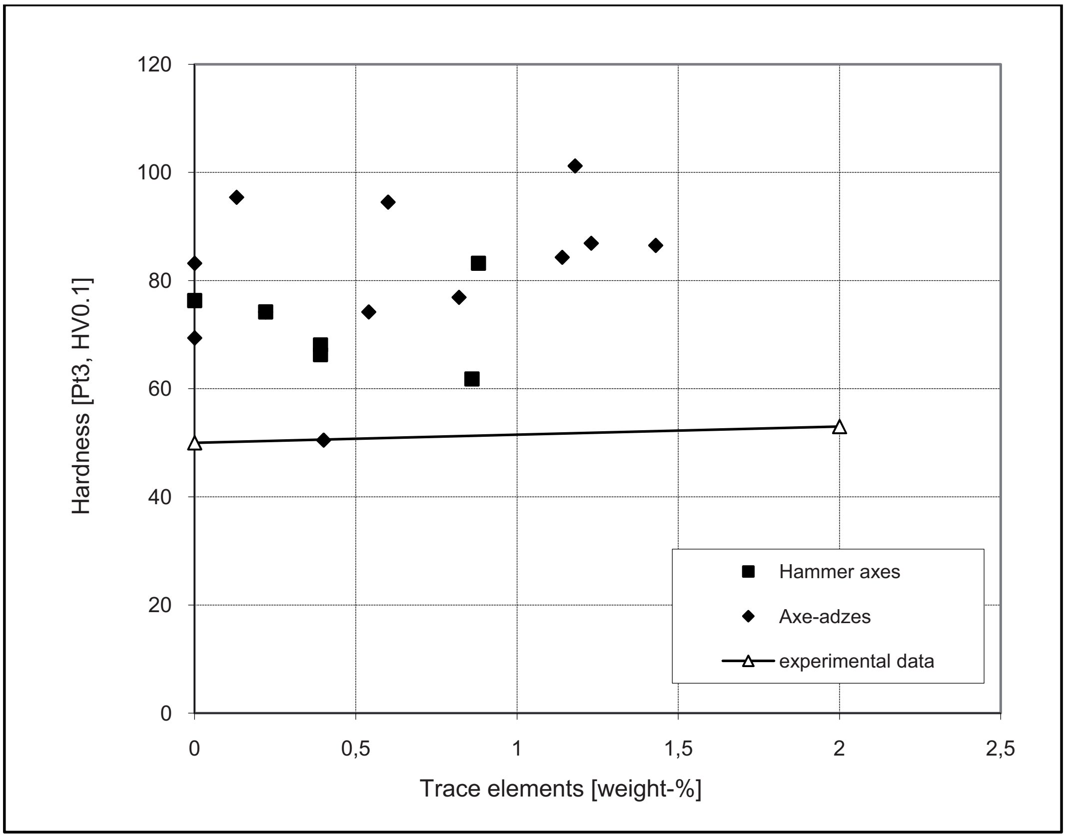


Fig. 3.26: The influence of the (Cu+Cu$_2$O)-eutectic on the hardness of Eneolithic/Copper Age hammer axes and axe-adzes without cold work (hardness at the back [pt. 3 = core] of the samples without any traces of deformation due to either use wear or cold work; experimental data after Lechtman 1996).

few younger axes with this oxide type there are pieces with substantial cold work (see chapter 4.3). So, in principle it was possible to cold work axes with the (Cu+Cu$_2$O)-eutectic oxide type, especially within the rather narrow limits set by the Eneolithic/Copper Age approach to forging described above.

We are left with the conclusion that there is no clear-cut decision between an explanation drawing on 'cultural' factors and one referring to material properties. It is unlikely that the (Cu+Cu$_2$O)-eutectic *necessitated* hot working. Yet by referring back to its influence on hardness discussed above there is a reason why its presence might have *favoured* this approach. The presence of the (Cu+Cu$_2$O)-eutectic, leading to reduced deformability and additional hardness, encouraged an emphasis on easy shaping at high temperatures. Forging was carried out by this method to make up for reduced deformability. But for the same reason – the additional hardness the (Cu+Cu$_2$O)-eutectic provided – durability of the axes was felt to be sufficient. 'Deficiencies' in casting (high amount of [Cu+Cu$_2$O]-eutectic) discouraged attempts at optimizing hardness by way of forging technique (cold working). The presence of the (Cu+Cu$_2$O)-eutectic provided an alternative mechanism to improve performance by – unconsciously – benefiting from actual 'shortcomings' in casting technique.

4
Traditions under Transformation I: The Casting and Working of Eneolithic/Copper Age Flat Axes

In the previous chapter an outline was given of the production of different types of Eneolithic/Copper Age shaft-hole implements. Some general characteristics of casting and working these axes were established, and a specific tradition or technological 'style' was identified that relied on working these implements at high temperatures for shape. Hardness was of minor interest, at least as far as the possibility of work hardening is concerned, and was a secondary outcome of deficiencies – from a modern perspective – in casting technique instead. However, this should not be taken as evidence of 'primitive' technology or a lack of understanding on part of the metalworkers involved. Rather we encounter a tradition that was already well established, and in its given context was fully adequate, both with regard to the metallurgical knowledge involved, which remained stable for a considerable period of time, and to the requirements put upon those involved in the practice of metallurgy by their communities.

In this chapter transformations will be examined that eventually occurred and correspond to a decline in the production of heavy shaft-hole implements during the later Eneolithic/Copper Age. To this end it is necessary to turn to another group of objects, namely copper flat axes, which make their first appearance broadly contemporaneously to the shaft-hole axes discussed above but remained in use much longer. Hence, in this chapter we will distinguish between two horizons of Eneolithic/Copper Age flat axes, and their respective microstructural evidence will be discussed. It will be shown that in both horizons close control over basic production steps was achieved. Comparable to the shaft-hole implements the metallographic data suggests that in the production of flat axes there were few differences in overall approach to casting and forging throughout the Carpathian Basin. Furthermore, axes of different (archaeological) types were produced in essentially the same way. On the other hand, there are differences between the production of broadly contemporary shaft-hole axes and flat axes during the Early to Middle Eneolithic/Copper Age, our horizon 1. In addition, meaningful patterning is also found that divides the flat axes of our older and younger Eneolithic/Copper Age horizons 1 and 2. In spite of discussions on the precise date or cultural affiliation of some of the axe types involved, the microstructural evidence confirms the existence of two distinct horizons with marked differences in casting and forging technique. An attempt will be made to account for this finding. Its implications will be discussed in terms of the perception and manipulation of the properties of different types of copper, namely rather pure copper and arsenical copper, used during subsequent phases of the Eneolithic/Copper Age. Finally, in chapter 5 the microstructural findings will be contextualised and their implications for the function and the meaning of the axes considered. This will also involve broadening the discussion to the role of copper in Eneolithic/Copper Age society. In the final section of that chapter, against the background of a wider anthropological perspective, a model is put forward to account for both aspects of the data discussed in chapters 3 and 4. How uniformity in some basic parameters came about on the one hand; and how horizon 2 innovations spread in Middle to Late Eneolithic/Copper Age society on the other.

4.1 Eneolithic/Copper Age Flat Axes: Chronology, Distribution and Data of this Study

4.1.1 Horizon 1: Flat Axes of the Early to Middle Eneolithic/Copper Age

Among the 20 axes sampled in this group there are such of Szakálhát, Stollhof, Stollhof-Hartberg and Split type (or variant) and related forms (fig. 4.1), which are characteristic of the Early to Middle Copper Age in Hungarian terminology (Patay 1984, 7 fig. 1; Parzinger 1993, 263–267, 345–348). Generally speaking, horizon 1 flat axes are slim and rather lengthy, of almost rectangular to wedge-shaped outline with a more or less heavily curved blade. There is substantial variation in details of size, cross-section (symmetrical vs. asymmetrical) and outline, especially of the neck and cutting edge. In addition such forms occur over a wide geographical area. This is why they were divided by archaeologists from different countries into several types and variants, often with similar pieces occuring under different names or, conversely, with quite different forms included in the same type (cf. Novotná 1970; Vulpe 1975; Mayer 1977; Todorova 1981; Patay 1984; Dobeš 1989; Říhovský 1992; Žeravica 1993).

M. Novotná (1970, 14–19), for example, in Slovakia

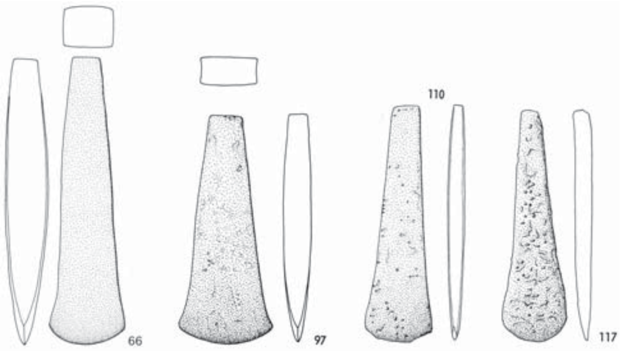


Fig. 4.1: Types of Eneolithic/Copper Age horizon 1 flat axes examined in this study (from left to right: group 1/Stollhof etc. [Říhovský 1992, 58 no. 66, tab. 8.66], group 2/Hartberg etc. [Mayer 1977, 46 no. 97, tab. 9.97], group 3/Szakálhát etc. [Mayer 1977, 50 no. 110, tab. 10.110] and group 4/Split etc. [Mayer 1977, 51 no. 117, tab. 10.117]).

subsumed all horizon 1 axes into one category, her 'schmale Kupferbeile', separating them from a group of broader axes, her 'breite Kupferflachbeile' of Altheim type etc. These correspond to horizon 2 of the present study (see below). A. Vulpe (1975, 55–63) took a similar approach to the Romanian material, but in his group of 'schmale Flachbeile' he singled out a number of variants, e. g. Gumelniţa, Coteana and Sălcuţa, which match – although under different names – axes discussed here from the north-western fringes of the Carpathian Basin. In his work on the Austrian axes, which is directly relevant since it includes a number of axes sampled for the present study, E. F. Mayer (1977, 45–53) took an axe from the Austrian Stollhof hoard (fig. 2.11) to label a group of flat axes comparable to Vulpe's (1975) varieties mentioned. Both Mayer's type Stollhof and Vulpe's variants Gumelniţa etc. have close parallels in the (possible hoard) finds from Vinča period Pločnik, hence this site, too, became eponymous, and such axes are also known as type Pločnik with variants Kobeřice, Stollhof and Strážnice (see also Dobeš 1989, 39–40).

Mayer (1977, 45–46) further took a (possible hoard) find from Hartberg, Austria, to define a more sturdy, trapezoid variant of Stollhof type axes. He accepted an earlier proposal by P. Patay in defining another large group of axes as type Szakálhát after a grave find from the eponymous cemetery in Hungary (Mayer 1977, 50–51). Mayer's axes of this latter group, however, in part show substantial deviation from Patay's (1984, 24–30) Szakálhát type axes proper (see also Dobeš 1989, 39–41, fig. 1). The same is true for Split type axes that take their name from a Croatian hoard (Mayer 1977, 51–52; Žeravica 1993, 55–56), but can be seen to have quite different characteristics, for example, in the studies of Mayer (1977), Z. Žeravica (1993) and M. Dobeš (1989, 39–41). Finally, apart from the volumes of the 'Prähistorische Bronzefunde' series already mentioned, there is the one by J. Říhovský (1992) covering Moravia. A number of axes from this region were sampled. However, while it is internally consistent, Říhovský's (1992) revision of traditionally agreed types is rejected (e. g. group III, type 2a, variant Bb for an axe of type Stollhof), since it is even more confusing than the problems caused by the inconsistencies of 'traditional' typologies and naming outlined above.

The best supra-regional classification of Eneolithic/Copper Age flat axes is doubtlessly provided by M. Dobeš (1989), who avoids the problems of the PBF approach caused by data presentation according to modern countries and a heavy emphasis placed on minor regional variation (fig. 4.2).

However, to avoid confusion and conflicting terminology with earlier publications, no standardisation in terms of Dobeš' (1989) types/variants was undertaken for this volume. Instead, in appendix II the axes' type or variant according to PBF is given, but they were arranged into four large groups reflecting broad formal similarity. Thus, group 1 comprises one of Mayer's (1977, 52) 'kleine Flachbeile' and axes from Říhovský's (1992) groups I (type 2a, var. Bb and type 2b, var. Bb) and III (type 2a, var. Bb). All of them belong to the broadly defined group of Stollhof type axes according to Mayer (1977) or Pločnik type, variants Kobeřice etc. according to Dobeš (1989). In group 2 there are axes of type Stollhof, variant Hartberg as defined by Mayer (1977), in addition one of his 'kleine Flachbeile' and one of Novotná's (1970) 'schmale Kupferbeile', which also fall into this group, as well as two axes from Říhovský's (1992) groups III (type 2a, var. Bb) and V (type 2a, var. Bb). There is some variation here and smooth transitions from Stollhof to Stollhof-Hartberg (Mayer 1977) or Pločnik-Kobeřice/Stollhof/Strážnice to Boljun-Hartberg (Dobeš 1989). But the axes included here are felt to be closer to the Hartberg side (Mayer 1977: type Stollhof, variant Hartberg; Dobeš 1989: type Boljun, variant Hartberg). We will see anyway that such formal variation reflects 'culture' in the widest sense, that is a concern with size, shape and function, but it did not affect 'technology' of the axes as seen through their microstructures. Group 3 was arranged around two Szakálhát type axes listed by Mayer (1977), complemented by two axes from Říhovský's (1992) groups III (type 2a, var. Bb) and V (type 2a, var. Ab). Again, there is some formal variation in this group, and some of the Szakálhát type axes in the sense of Mayer (1977) are more or less atypical in terms of the definition of this type provided by Patay (1984, 24–30; see above) and subsequently applied, amongst others, by Dobeš (1989, 39–41, fig. 1: type Boljun, variant Szakálhát). Finally, in group 4 there are two Split type axes published by Mayer (1977) as well as one piece classified by this author as one of his 'kleine Flachbeile' but showing related features. Here, too, there is variation, and the axe with sample no. 92, in particular, would not in the definition of Dobeš (1989, 39–41) qualify as type Dugo Selo, variant Split. One last piece, the axe with sample no. 55 from the hoard of Malé Leváre (see fig. 3.8), was set apart ('group' 5) for its formal characteristics that lead up to the younger Altheim type axes of horizon 2 (for discussion see below).

Stollhof type axes (fig. 4.1; see appendix II), following the

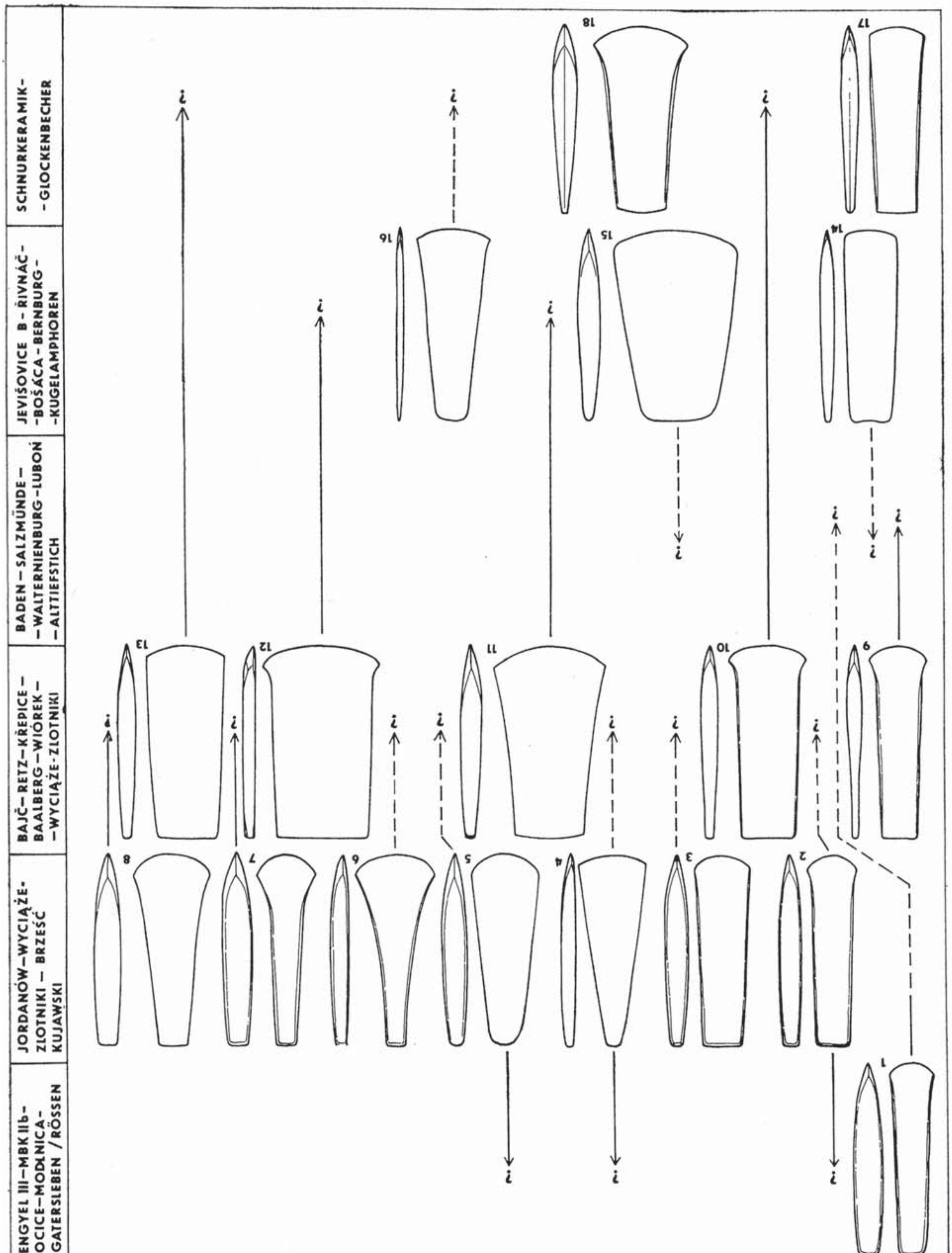


Fig. 4.2: Types and development of Eneolithic/Copper Age flat axes (after Dobeš 1989, 41 fig. 1).

definition by Mayer (1977, 45–48), are known from Austria, Bohemia and Moravia, Slovakia as well as from northern Italy (Novotná 1970, 14–18; Říhovský 1992, 55–66). Four of these axes sampled – in our group 1 – come from this area (sample nos. 123, 137, 140 and 156), the fifth one is of unknown origin (sample no. 84). However, axes of this form in a wider sense occur throughout large parts of south-eastern Europe including the Carpathian Basin and the Balkans, Bulgaria and Romania (e. g. Vulpe's 1975, 55–59 'schmale Flachbeile' of variants Gumelniţa, Coteana and Sălcuţa; Dobeš' 1989, 39–41 Pločnik type with variants Kobeřice, Stollhof and Strážnice; see also Todorova 1981; Žeravica 1993). They are thought to be the earliest copper flat axes in this area for typological reasons, and an early date from the local Late Neolithic or (Early) Eneolithic/ Copper Age onwards (see figs. 2.1 and 4.2; e. g. Lengyel III, Vinča-Pločnik/Vinča C–D, Tiszapolgár, Gumelniţa A1/ Gumelniţa-Karanovo VI) is confirmed by a number of find contexts (e. g. the 'hoards' from Pločnik – irrespective of their precise position – or settlement finds from Gumelniţa and Sokol; Vulpe 1975, 58–59; Dobeš 1989, 40–44; Říhovský 1992, 58; Žeravica 1993, 50–51; Parzinger 1993, 346 hor. 8, 348 hor. 9). A younger date and prolonged use of such axes into Bodrogkeresztúr times is indicated by the eponymous hoard of Stollhof in Austria (fig. 2.11; Dobeš 1989, 44; Matuschik 1996, 8).

The Stollhof hoard, however, also raises some chronological problems, because Mayer (1977, 47–48) suggested a Middle (Bodrogkeresztúr) or rather Late (Baden) Eneolithic/ Copper Age date for this find, which was tacitly accepted in subsequent volumes of the PFB-series (Říhovský 1992, 58, 61–62, 65; Žeravica 1993, 50–51, 129; Pászthory/Mayer 1998, 25). It is beyond dispute that all the axe types in question were in use over a considerable period of time. But this touches upon problems of both dating individual axes as well as Eneolithic/Copper Age chronology in general. For example, Mayer (1977, 47 annot. 4) refers to a Stollhof type axe from the settlement of Barca to apply a Baden date to this form. He quotes Novotná (1970, 14 no. 9) to support this assumption, although she makes it quite clear that this piece is from the lower boundary of Baden layers at this site and the pottery is not properly published (Novotná 1970, 16; cf. Dobeš 1989, 44; Parzinger 1993, 348). More generally, between Bodrogkeresztúr and Baden there are the *Furchenstichkeramik*, Hunyadi-halom, *Scheibenhenkel* and (proto-) Boleráz etc. groups/horizons (Patay 1984, 7 fig. 1; Pavelčik 1991; Kalicz 1991, 362–381; 2001, 398–408; Raczky 1991, 332–341; Horváth/Simon 2003, 124–138). The situation is quite complex, especially when trying to correlate cultural sequences of the north alpine region and the north-western periphery of the Carpathian Basin with Hungarian developments (Parzinger 1992, 246–249; 1993, 265–272, 290; Lenneis/Neugebauer-Maresch/Ruttkay 1995, 10, 129–160; Matuschik 1996, 2–11; 1997, 96–102; Maran 1998, 347–355; Klassen 2000, 93–209). It should be noted, however, that contact with some kind of pre-, proto- or early Baden horizon of considerable duration itself would not render the Stollhof type axes typically Late Copper Age, in the sense of proper Baden (Dobeš 1989, 44). The eponymous hoard of Stollhof is firmly linked by its second axe (type Stollhof, variant Hartberg; Mayer 1977, 46–47 no. 98), gold discs and *Brillenspiralen* of copper and gold to the horizon of Jordanów/Jordansmühl, Brešć-Kujawski and Bodrogkeresztúr (Novotná 1970, 16; Parzinger 1992, 247–248; Matuschik 1996, 7–8; 1997, 98–99; Klassen 2000, 194–196, 241–242; 2010, 31–32). For this reason Stollhof type axes as well and related forms (Říhovský 1992; groups I, III and V) were grouped into horizon 1 (see also Dobeš 1989, 40–44; Parzinger 1993, 348–349; Klassen 2000, 98–105). Some overlap between these forms and our horizon 2 axes is possible (Novotná 1970, 18; Dobeš 1992, 335–337), but from the archaeological evidence discussed (i. e. axes from closed finds such as graves and hoards) they certainly represent an earlier development. This tends to be confirmed by the microstructural findings discussed below.

Axes of variant Hartberg (of type Stollhof or type Boljun; Mayer 1977, 45–48; Dobeš 1989, 40–41, fig. 1), our group 2, have a wide distribution from parts of Germany via Austria to the Carpathian Basin (fig. 4.1; see appendix II). One of the axes sampled is from the eponymous hoard(?) from Hartberg, Steiermark (Austria; sample no. 77), two axes are from today's Czech Republic (sample nos. 122 and 157), another piece is from Slovakia (sample no. 49) while the remaining ones are of unknown origin (sample nos. 86, 103 and 106). They come from the same Vienna collection mentioned earlier, which can imply an origin somewhere further east in the Carpathian Basin (see chapter 3.1). In the hoard of Kladari-Karavid, Bosnia, an axe of this variant was recovered together with an axe-adze of type Kladari and a number of Gurnitz type flat axes, which points to a Middle Copper Age date in Hungarian terminology, i. e. Bodrogkeresztúr times (see also fig. 4.2). At Horodnica in Galicia a Hartberg variant axe was found in association with a Jászladány type axe-adze, which implies the same broad date, although the pottery of this find is thought to be somewhat later and date to Cucuteni B. This would indicate a longer lifespan of this type/variant (Mayer 1977, 46–47; Patay 1984, 34–37; Dobeš 1989, 44; Říhovský 1992, 61–62, 65–66; Žeravica 1993, 19, 50–51, 53–54).

Most variants of Szakálhát type axes as defined by Patay (1984, 24–30) are well documented in the area of the Bodrogkeresztúr culture, namely the Great Hungarian Plain and parts of Transylvania, with individual pieces found well beyond this region, for example in Transdanubia, Slovakia and Austria. The axes sampled, our group 3, belong to this latter group (fig. 4.1; see appendix II): Sample no. 46 may come from a hoard in Linz, Austria, where it was recovered together with hammer axe of Székely-Nádudvar type (see chapter 3.1; Mayer 1977, 10 no. 9, 50 no. 111), while sample nos. 120 and 121 are stray finds from places in today's Czech republic. Sample no. 108 is of unknown origin, and may be the only piece in this group to come from the main distribution area of Szakálhát type axes in the Carpathian Basin. Axes of the Szakálhát type are known, in some number, from graves of the Bodrogkeresztúr culture (fig. 4.3) and hoards such as Szeged-Sziller (see fig. 2.9; Patay 1984, 24–30). They are firmly linked, therefore,

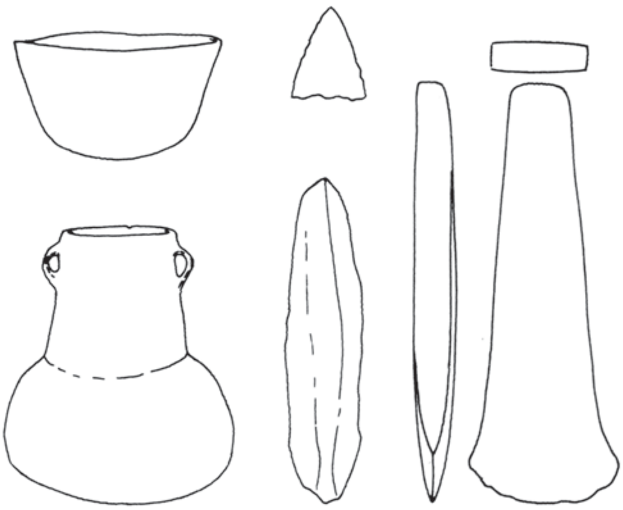


Fig. 4.3: A flat axe of type Szakálhát from a grave of the Bodrogkeresztúr culture at Fényeslitke, Hungary (grave 21; after Patay 1984, 27–28 no. 57, tab. 68B).

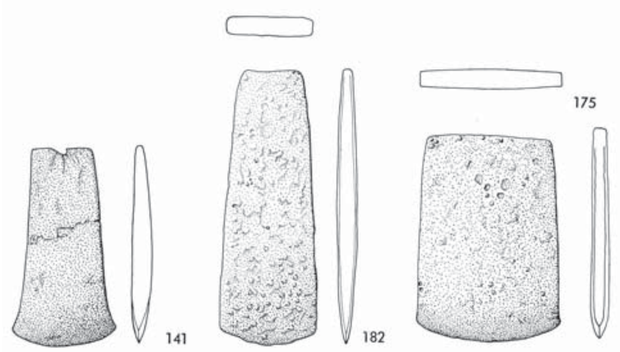


Fig. 4.4: Types of Eneolithic/Copper Age horizon 2 flat axes examined in this study (from left to right: Altheim [Mayer 1977, 55 no. 141, tab. 11.141], Vrádište [Mayer 1977, 65 no. 182, tab. 13.182] and Vinča [Mayer 1977, 64 no. 175, tab. 13.175]).

to the Middle Copper Age in Hungarian terminology (*Hochkupferzeit*, Patay 1984, 7 fig. 1) and contemporaneous groups of Parzinger's (1993, 347–348) horizon 9 in adjacent areas (see also fig. 4.2; Novotná 1970, 16–18; Mayer 1977, 50–51; Dobeš 1989, 40–44; Říhovský 1992, 61, 65; Žeravica 1993, 55).

Finally, three Split type axes of unknown origin were sampled (sample nos. 92, 109 and 110; see fig. 4.1 and appendix II). Axes of this type take their name from an eponymous hoard find close to Split in Croatia, and they are best known from the Balkans and along the Adriatic coast from Istria to Montenegro with individual finds well beyond this area. In the eponymous hoard two such axes were associated with a hammer axe of type Čoka and two axe-adzes of Mugeni and Jászladány type (Gripe/Split: Žeravica 1993, 9 no. 12, 11 no. 13, 14 no. 24, 55–56 nos. 158 and 159), which confirms their dating to the Bodrogkeresztúr horizon (Mayer 1977, 51–52; Dobeš 1989, 44; Říhovský 1992, 61–62, 65; Žeravica 1993, 55–56).

4.1.2 Horizon 2: Altheim and Vinča Type Axes of the Later Eneolithic/Copper Age

Flat axes of horizon 2 tend to be shorter and of a more sturdy shape than horizon 1 axes and have a slightly trapezoidal to rectangular outline (fig. 4.4). Their cutting edge is slightly curved, their neck is straight and their cross-section is symmetrical. Less commonly, as with Vinča axes the cross section is asymmetrical. For this study samples could be obtained from 19 horizon 2 flat axes. Comparable to horizon 1 there is formal variation in details of size and shape (e. g. Novotná 1970; Říhovský 1992; Žeravica 1993), but the axes sampled can be assigned to Altheim, Vrádište and Vinča types in their broadest sense (see appendix II; Mayer 1977, 53–65; Dobeš 1989, 40–41). In addition, there is metallographic data for another nine Altheim type axes that were already included in a previous study (Kienlin/Bischoff/Opielka 2006; Kienlin 2008a).

The main occurrence of Altheim type axes is in Austria, where they are well-known from the lakeside settlements of Mondsee and Attersee. In addition, Altheim axes or related forms can be found in a wide area from Switzerland and southern Germany in the west as far as the Balkans in the east (Mayer 1977, 62–63; Říhovský 1992, 71–73). A number of axes examined from Mondsee and Attersee were previously published in detail (Kienlin 2008a, 93–111; see also Budd 1991a). The results of this earlier study are integrated into the discussion of the microstructural evidence of horizon 2 flat axes in chapter 4.3 (sample nos. 504003, 504401, 504403, 504404, 504405, 504406, 504407, 504501 and 504502 from Kienlin 2008a). Additionally, ten Altheim type axes were sampled for the present study, which for the most part come from the Czech Republic, with one piece from Austria, Germany and of unknown provenance respectively (fig. 4.4; see appendix II). Vinča type axes, too, have a wide distribution from Austria to the Carpathian Basin and the Balkans in the east (Mayer 1977, 63–65; Říhovský 1992, 73–75; Žeravica 1993, 57–58). Six axes of this type were sampled (see appendix II). One of these in known to come from Moravia (sample no. 99), while for the remaining ones no information on their provenance is available. With regard to the Vienna collection these pieces are kept in it is possible that some/all of them come from the Carpathian Basin or the Balkans. Vrádište type axes strongly resemble Altheim and Vinča axes – depending on their specific variant and characteristics (fig. 4.4). Correspondingly, they have a wide distribution throughout south-eastern Europe as well with some clustering on the north-western fringes of the Carpathian Basin (Mayer 1977, 65). The three pieces sampled come from the area of today's Austria, Slovakia and the Czech Republic (see appendix II).

This group of axes is thought to represent a more recent development for both archaeological and compositional reasons (fig. 4.2; Novotná 1970, 17–18; Patay 1984, 10–12; Dobeš 1989, 44–45; 1992, 337–338). On the other hand, it is subdivided in a number of different types and/

or variants, which – especially in the Altheim case – are supposed to cover a substantial period of time from the Middle (Bodrogkeresztúr) Copper Age to the Early Bronze Age (Mayer 1977, 60–65; Pászthory/Mayer 1998, 26). The problems involved in positing an early beginning of this form are illustrated by an axe from the hoard of Malé Leváre that anticipates features of the Altheim type (fig. 3.8). This hoard is characteristic of the Bodrogkeresztúr etc. horizon (see above in chapter 3.1). Novotná (1970, 14, 16–18) argues that there are rare older forms – related but not identical – actually leading up to the (somewhat younger) Altheim type axes proper. For this reason and its otherwise uncontested Middle Eneolithic/Copper Age date the axe from Malé Leváre was included in our horizon 1. Mayer (1977, 48, 60), however, assigns this piece to type Altheim proper, but he prefers a late date for Stollhof (see above), and correspondingly Malé Leváre is supposed to belong to the Baden culture (see also Pászthory/Mayer 1998, 26). Axes of Vrádište type, on the other hand, represent a somewhat younger development and form closer to Altheim (Novotná 1970, 15 no. 37; Mayer 1977, 65). The eponymous piece from Vrádište was found in a settlement with *Furchenstichkeramik* formerly known as type Gajary (Novotná 1970, 16; Mayer 1977, 65), which represents a pre-Boleráz development (Dobeš 1989, 44–45; Parzinger 1993, 265; Lenneis/Neugebauer-Maresch/Ruttkay 1995, 10, 138–145; Klassen 2000, 196–197). Because of their form and this date the Vrádište type axes were included in horizon 2. As far as their (relative) position is concerned they are supposed to be contemporaneous with (younger) horizon 1 axes (see above).

From the settlement of Altheim in Bavaria, the eponymous site of both the Altheim culture and axes, there is only one axe of this type known (Pászthory/Mayer 1998, 25). A larger number of Altheim axes were recovered from the well-known lakeside settlements of Mondsee and Attersee in Austria (Franz/Weninger 1927; Willvonseder 1963/68; Obereder/Pernicka/Ruttkay 1993; cf. however Klassen 2000, 126). The Altheim and Mondsee cultures as well as Pfyn further west belong to the Late Neolithic of the north alpine region (fig. 2.4; *Jungneolithikum*; Lüning 1996). The horizon they represent is of some duration and not easily correlated with cultural sequences in the Carpathian Basin (figs. 2.1 and 2.3; see chapter 2.1). The early development of Altheim and Mondsee is synchronised with the Hunyadi-halom, *Furchenstichkeramik* and (proto-) Boleráz etc. horizon. During their later phase Altheim and Mondsee are supposed to be contemporaneous with (early Baden-) Boleráz (Matuschik 1996, 8, 10–11; 1997, 98–99; Maran 1998, 348–349). Evidence for the even younger use and production of Altheim and Vinča type axes comes from (late Baden-) Kostolac layers in the settlement of Vučedol and – subsequently – their appearance in Final Copper Age Vučedol and Jevišovice B etc. contexts. Some variants apparently remained in use till Bell Beaker and Early Bronze Age times (Novotná 1970, 18–19; Mayer 1977, 60–62, 64; Dobeš 1989, 45; Říhovský 1992, 71–72, 75; Žeravica 1993, 57–58; Ruprechtsberger/Urban 1996/97, 162; Pászthory/Mayer 1998, 26; Klassen 2000, 126, 135–137).

In absolute terms, then, this gives the late 5th and early 4th millennium cal BC for Tiszapolgár, Bodrogkeresztur and contemporaneous groups; our horizon 1 axes. Pfyn, Altheim and Mondsee make their appearance somewhat later during the first half of the 4th millennium, around 3800 cal BC, initially synchronised with Hunyadi-halom and proto-Boleráz etc.; our horizon 2 axes. After 3600 cal BC their development continues parallel to (early Baden-) Boleráz well into the second half of the 4th millennium BC (Matuschik 1996, 10–11; 1997, 98–99; Maran 1998, 348–349). The Vučedol sequence succeeding (late Baden-) Kostolac is dated by J. Maran (1998, 350–351, 354, tab. 82) from about 3000 cal BC to 2500 cal BC, when it is replaced by Early Bronze Age groups – in Hungarian terminology – such as Makó. From the above discussion on relative chronology it is possible that the use of horizon 1 and 2 axes overlapped. The absolute dates show that this is likely to be the case some time prior to the middle of the 4th millennium BC (Dobeš 1992, 336–337; Klassen 2000, 103, 135–137). They also show, however, that horizon 1 axes started and reached their climax distinctly earlier, while horizon 2 axes remained in use considerably longer. Our metallographic data show that both horizons may be separated on basis of distinct differences in casting technique and methods of working.

4.2 Traditions: The Metallographic Evidence of Horizon 1 Flat Axes

The overall impression from this earlier group of Eneolithic/Copper Age flat axes is that of their manufacture being in good accordance with the contemporaneous hammer axes and axe-adzes discussed above (see chapter 3). The same basic routines were followed and decisions taken in the production of all three groups of artefacts. But within this broad tradition there occurred minor variations during the casting process that demonstrate differences in emphasis in the production of shaft-hole implements and flat axes. The resulting variation in oxide contents may relate to the technical requirements on casting the more complex shaft-hole implements and/or it may reflect different meaning and value attached to both groups of objects (see also chapter 5.1).

All but one sample in this group of early flat axes have a fully recrystallised microstructure (figs. 4.5 and 4.6 M8; see also the corresponding tables in appendix II). The only possible exception is sample no. 103, an axe of type Stollhof (-Hartberg). In this case there are large irregularly formed grains, and in some parts of the sample only there are the smaller grains with straight grain boundaries and twinning characteristic of a recrystallised microstructure. Upon closer examination the recrystallised areas tend to cluster along the surface, grain boundaries, pores and oxide inclusions – all of these are areas of high energy that favour recrystallisation at rather low temperatures and/or upon only short-term exposure to high temperatures (Schumann

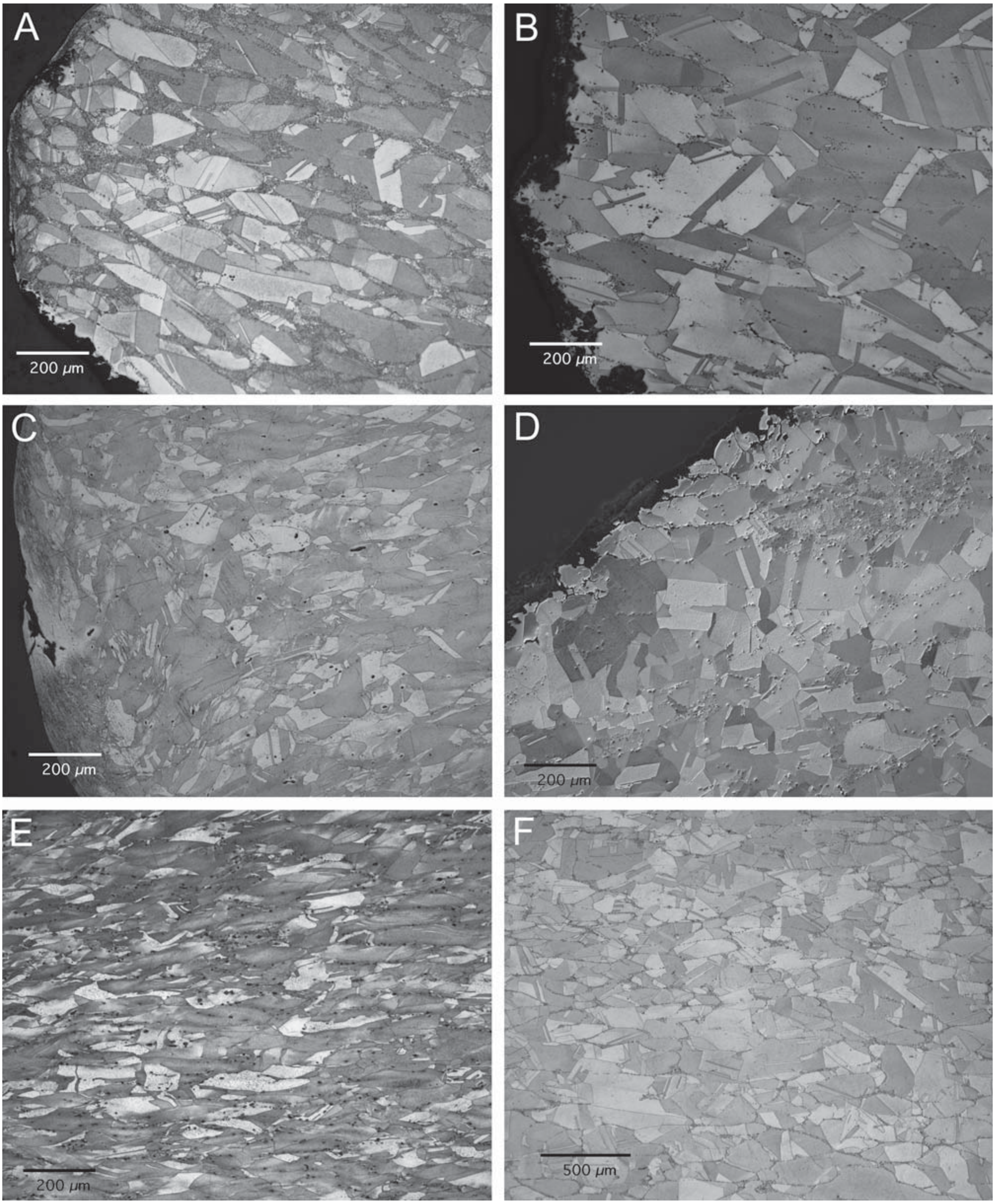


Fig. 4.5: Characteristic microstructures of Eneolithic/Copper Age horizon 1 flat axes examined for this study (A: sample no. 109; B: sample no. 49; C: sample no. 157; D: sample no. 123; E: sample no. 122; F: sample no. 106).

1991; Kienlin 2008a, appendix I). Typically, however, there are larger irregularly formed grains without twinning, which are best interpreted as casting grains, and there is coring which underlines the fact that exposure to higher temperatures was of much lower intensity than is usually the case in this group of axes. Coring, oxide inclusions and some porosity still maintain the dendritic outline of the original as-cast microstructure. The axe in question did not receive the thorough kind of working and finish that is typically seen in this group but at best was subject to a very superficial forging. This might have involved the application of heat that caused partial recrystallisation. But

most likely this did not take the form of (or was perceived as) a separate production step, be it hot work or annealing. Still, there are traces of wear at the tip of the sample (= cutting edge), and some slightly deformed twins, few grains with strain lines and an increase in hardness towards the cutting edge (140 HV at point 1 as opposed to 108.2 HV at point 3; see fig. 4.7) that are best interpreted as a result of surface finish and use.

Sample no. 103 shows that in spite of being essentially unfinished from a microstructural point of view, in the sense that is was not properly worked according to the standards of this group of Eneolithic/Copper Age axes, it was possible for individual axes to go into use more or less directly after casting. Some slight surface finish was required. But in principle with the casting method involved and care given in its operation it was possible to cast close to the final shape required (see also chapters 3.4 and 4.4 on the use of closed moulds). However, the majority of horizon 1 flat axes, like contemporaneous hammer axes and axe-adzes, after casting received a generally thorough working. In all samples there is (ample) twinning in most grains that provides evidence, from the copper matrix perspective, of the working that took place and that it typically affected the whole sample area (figs. 4.5 and 4.6 M9). This procedure may have involved the removal of casting seams and the smoothing of surface defects. It is also possible that the smiths were aware that during this process pores were closed thereby reducing the risk of breakage and improving the mechanical properties (fig. 4.6 M1).

Following the argument outlined for contemporaneous hammer axes and axe-adzes in chapter 3.5, it is likely that this forging was carried out at high temperatures (see below), and unlike the generally younger flat axes of horizon 2, certainly no attempt was made to benefit from work hardening. In five samples of horizon 1 flat axes (sample nos. 46, 49, 109, 121 and 137) there is no evidence of final cold work at all. In another 14 microstructures there is some superficial deformation that is most likely related to surface finish and/or use (figs. 4.5 and 4.6 M13–16). An excellent example of use wear in the latter group is provided by sample no. 123 with deformed grains and strain lines extending backwards from the tip of the sample (= cutting edge) for just about 500 µm. This is the only sample with deformed grains in this group. More often there are just some slightly deformed twins at the cutting edge and along the surface. Their frequency and distribution rule out any deliberate cold work through hammering. This deformation is far from affecting the whole sample, and it is best interpreted as a side-effect of surface finish by grinding and polishing and/or indicative of some use of limited intensity. In figure 4.8 this group of axes is shown under the heading of “twins deformed/strain lines [*use wear*]”. In figure 4.6 (M16) a number of these pieces carry the specification 0 %*?* to indicate very low frequency of just some slightly deformed twins and doubts on the presence of (cold) deformation at all along any significant part of the sample’s surface. On the other hand, 5–10 %*?* or 10–20 %*?* refer to a somewhat higher frequency of deformed twins and/or a slightly larger sample area showing this feature, which is nonetheless thought unlikely to represent cold *work* proper in the sense of a separate (final) production step.

It is only in sample no. 55 that there are mildly deformed grains in a larger part of the sample. Accordingly this axe is classified with a (cold) deformation level in the 35 % to 40 % range (fig. 4.6 M16). At the cutting edge there is additional use wear that clearly adds to this feature, but deformed grains extend further back than might be expected from use wear alone. Deformed twins throughout the whole sample area indicate that in fact cold work took place. Among the axe-adzes, too, there is one exception to the general absence of deliberate cold work in the final step (sample no. 177-1/2; see chapter 3.3). We are talking about broad traditions of metalworking in a premodern context of ‘traditional’ handicraft, hence some variation is to be expected. The presence or absence of cold work generally is a good guide to distinguish microstructures from both Eneolithic/Copper Age horizons discussed, however microstructural evidence must not be used to date individual artefacts. There is a correlation between object type (date/horizon) and microstructure, but there is also a potentially quite long overlap between horizons. However, since sample no. 55 is the only piece with evidence of cold work among the horizon 1 flat axes examined, it is worthwhile to refer back to the dating problems surrounding the hoard of Malé Leváre from which this axe was recovered (see chapters 4.1.1 and 4.1.2).

If this hoard is indeed characteristic of the Bodrogkeresztúr etc. horizon, the axe with sample no. 55 would anticipate features of the Altheim type and lead up to the somewhat younger Altheim type axes proper (cf. Novotná 1970, 14, 17–18). Alternatively, axe no. 55 could represent the ‘true’ date of deposition, and the remaining finds from Malé Leváre already were rather old when they were buried alongside an Altheim type axe (cf. Mayer 1977, 48, 60; Pászthory/Mayer 1998, 26). This question cannot be answered, but more importantly this kind of approach tends to conceal that neither typology nor the metallurgical horizons suggested in this study mark any fixed point in time or clearly delineate a period. Instead they represent broad horizons, potentially with significant overlap. It should come as no surprise to find both ‘old’ and ‘young’ types and technology in association. A find like Malé Leváre is of interest not for the attempt to pin it down either early or late in this transition, but for the proximity of both technological traditions that it illustrates, and if in fact it is early, for the parallel devolpment in both form and technology.

Modern concepts of recrystallisation, the formation of new grains upon heating, as opposed to an additional homogenisation upon prolonged exposure to higher temperatures certainly were unknown to Eneolithic/Copper Age metalworkers. But the results of these microstructural changes were recognised, at least that of recrystallisation, and applied at intervals to restore deformability (called

Sample no.	Porosity, phases and inhomogeneities						Production steps						Final cold work					Total working		
	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20
Eneolithic/Copper Age flat axes, horizon 1 (type/group)																				
46 (type/group 3)	0	2.19%	a	x	0	0	0	xx	xx	x	xx	xx	0	0	0	0%	0	(x)	-	<<50%
49 (type/group 2)	0	1.86%	a	x	0	0	0	xx	xx	x	xx	xx	0	0	0	0%	0	(x)	-	<<50%
55 (type/group 5)	0	2.34%	(b)	x	0	(x)	0	xx	xx	xx	x	x	x	x	0	35-40%	x	(x)	x	~50%
77 (type/group 2)	(x)	2.54%	a	x	0	0	0	xx	xx	x	xx	xx	0	(x)	0	0%?	x?	(x)	-	<<50%
84 (type/group 1)	(x)	1.23%	(b)	x?	0	0	0	xx	(xx)	x	xx	xx	0	(x)	0	5-10%?	x?	(x)	-	<50%
86 (type/group 2)	x	7.22%	b	x	0	0	0	xx	x	x	xx	xx	0	(x)	0	0%?	(x)	(x)	-	<<50%
92 (type/group 4)	0	2.63%	a	x	0	(x)	0	xx	xx	x	x	x	0	x	0	10-20%?	x?	x	(x)	>50%
103 (type/group 2)	(x)	1.99%	b	0	0	x	x?	x?	x	x?	0	0?	0	(x)	(x)	0%?	(x)	(0)	(0)	<<50%?
106 (type/group 2)	0	1.08%	a	x	0	0	0	xx	xx	x	xx	xx	0	(x)	0	0%?	x?	(x)	-	<<50%
108 (type/group 3)	0	1.02%	a	x	0	0	0	xx	(xx)	x	xx	xx	0	x	x?	10-20%?	x?	(x)	-	<50%
109 (type/group 4)	0	3.95%	a	x	0	0	0	xx	xx	x	xx	xx	0	0	0	0%	0	(x)	-	<<50%
110 (type/group 4)	0	2.61%	(b)	x?	0	0	0	xx	xx	x	xx	xx	0	(x)?	0	0%?	(x)	(x)	-	<<50%
120 (type/group 3)	0	5.13%	a	x?	0	0	0	xx	x	x	xx	xx	0	x	0	5-10%?	x?	(x)	-	<50%
121 (type/group 3)	0	3.06%	a	x?	0	0	0	xx	xx	x	xx	xx	0	0	0	0%	0	(x)	-	<<50%
122 (type/group 2)	0	2.61%	a	x?	0	x	0	xx	x	x	x	x	0	x	0	10-20%?	x?	(x)	(x)	<50%
123 (type/group 1)	(x)	1.88%	a	x	0	0	0	xx	(xx)	x	xx	xx	(x)	0	(x)	0%?	x	(x)	-	<50%
137 (type/group 1)	0	1.1%	a	x	0	0	0	xx	xx	x	xx	xx	0	0	0	0%	0	(x)	-	<<50%
140 (type/group 1)	0	7.51%	a	x	0	0	0	xx	x	x	xx	xx	0	(x)?	0	0%?	0	(x)	-	<<50%
156 (type/group 1)	0	6.06%	a	x?	0	0	0	xx	xx	x	xx	xx	0	x	0	10-20%?	x	(x)	-	<<50%
157 (type/group 2)	(x)	1.47%	a/b	x?	0	(x)	0	xx	x	x	x	x	0	x	(x)	10-20%?	x	(x)	-	<<50%

Fig. 4.6: Microstructural features of the Eneolithic/Copper Age horizon 1 flat axes examined for this study. M1: porosity (0 = none/hardly any; x = occasionally; xx = frequent) – M2: oxides (% of sample area) – M3: kind of oxides (a = [Cu+Cu_2O]-eutectic; b = particles) – M4: influence of oxides on hardness (0 = none; x = yes/assumed) – M5: further phases (0 = none/hardly any; x = present) – M6: coring in copper matrix (0 = none/hardly any; x = weak residual coring; xx = heavily cored) – M7: casting grains (0 = none; x = present) – M8: recrystallisation (0 = none; x = partial; xx = complete) – M9: twinning (0 = none; x = frequent; xx = in most/all grains of sample area) – M10: production steps after casting (0 = none; x = as-cast, cold worked, or: cold worked, annealed, or: hot worked; xx = cold worked, annealed, cold worked, or: hot worked, final cold work) – M11: homogenisation (0 = none; x = partial; xx = complete) – M12: intensity of annealing/application of heat (0 = equi-axed grains; x: equi-axed grains, partly homogenised; xx: equi-axed grains, homogenised) – M13: deformation of grains (0 = none; x = moderate; xx = heavily deformed) – M14: deformation of twins (0 = none; x = moderate; xx = heavily deformed) – M15: strain lines (0 = none; x = one system; xx = duplex slip) – M16: strength of final cold work (% reduction in thickness, close to the cutting edge/tip of the sample) – M17: wear traces (0 = none; x = additional deformation at the cutting edge due to moderate use; xx = tip of the sample heavily deformed due to heavy use) – M18: deformation/breakage of porosity/oxides (0 = none; x = moderate; xx = heavily deformed) – M19: deformation of coring (0 = none; x = moderate; xx = heavily deformed) – M20: estimated total reduction in thickness (% reduction in thickness, close to the cutting edge/tip of the sample).

Sample no.	*HV pt1*	*HV pt3*	*Cu*	*S*	*Sn*	*Pb*	*As*	*Sb*	*Ag*	*Ni*	*Co*	*Fe*	*Bi*	*Sum TE*
Eneolithic/Copper Age flat axes, horizon 1														
46	60	68.8	99.7	-	-	-	-	-	0.3	-	-	-	-	0.3
49	76.9	74.2	99.6	-	-	-	-	-	-	0.1	-	0.3	-	0.4
55	140.7	109.8	99	-	-	-	-	0.6	0.4	-	-	-	-	1
77	92.4	77.6	99.6	-	-	-	-	0.2	-	-	-	0.2	-	0.4
84	107.2	92	99.2	-	0.2	-	0.4	-	-	-	0.2	-	-	0.8
86	86.1	79.2	96.5	-	-	-	0.9	-	0.5	1.1	-	0.6	0.4	3.5
92	106.6	100.3	99.8	-	-	-	-	-	-	-	-	0.2	-	0.2
103	140	108.2	99	-	-	-	0.4	-	0.4	-	0.1	0.1	-	1
106	81.2	80.5	99	-	0.2	-	-	0.6	-	-	0.2	-	-	1
108	103.2	83.2	99.8	-	-	0.2	-	-	-	-	-	-	-	0.2
109	90	92.8	100	-	-	-	-	-	-	-	-	-	-	0
110	90.4	67	98.7	-	-	0.2	0.2	0.3	0.6	-	-	-	-	1.3
120	94.1	102.2	99	-	-	-	-	0.6	0.4	-	-	-	-	1
121	74.8	79.8	99	-	-	-	-	0.4	0.3	0.3	-	-	-	1
122	88	88.8	99	-	-	-	-	0.8	-	0.2	-	-	-	1
123	85.4	74.2	99.5	-	-	-	-	0.4	-	-	-	0.1	-	0.5
137	68.6	57.1	99.8	-	-	-	-	-	0.2	-	-	-	-	0.2
140	100.8	85	97.8	-	-	-	1.4	0.5	-	-	-	0.3	-	2.2
156	90	102.7	99.5	-	-	-	-	0.5	-	-	-	-	-	0.5
157	117.7	105.6	98.2	-	-	-	-	0.7	0.9	-	-	0.2	-	1.8

Fig. 4.7: Hardness and composition of the Eneolithic/Copper Age horizon 1 flat axes examined for this study (Vickers microhardness HV0.1 at the tip of the sample [pt. 1 = cutting edge] and at the back of the sample [pt. 3 = core]; EDX analyses, weight-%, rounded to one decimal).

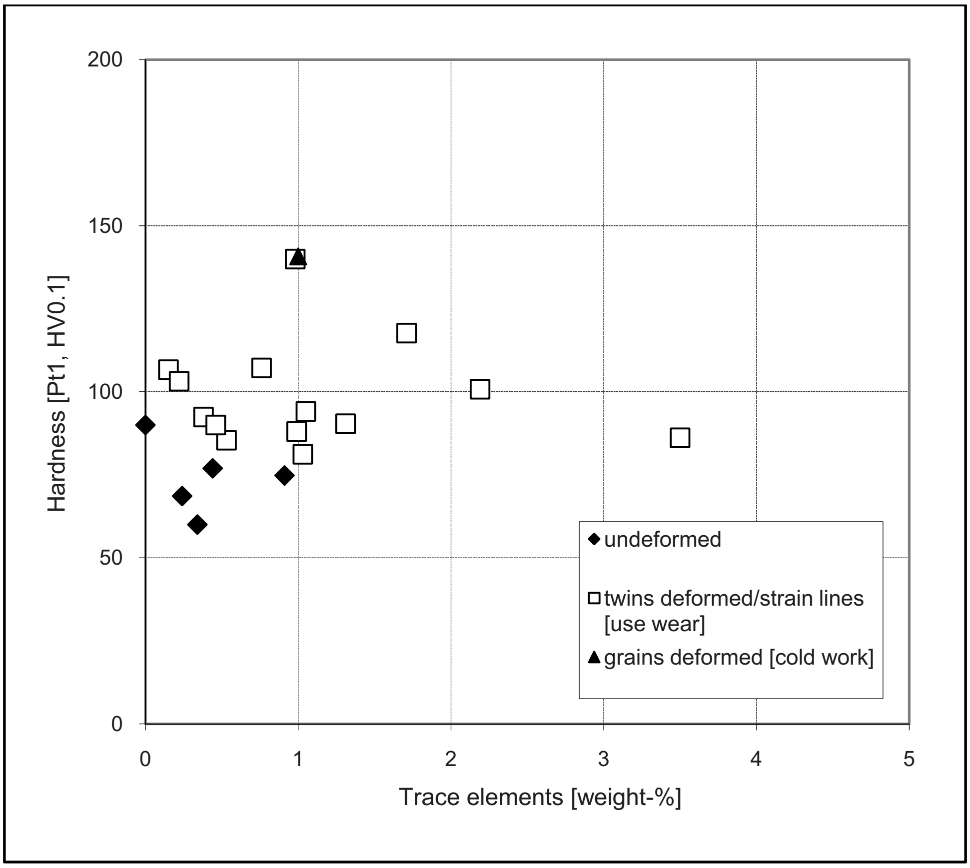


Fig. 4.8: The hardness of the Eneolithic/Copper Age horizon 1 flat axes, depending on composition and work hardening (surface finish/use wear) or cold work.

annealing) or to facilitate forging on a continuous basis (hot work). In modern practice inhomogenities are already removed prior to forging or rolling, which also has a positive influence on workability. But it is doubtful whether this effect was easily recognised under prehistoric conditions. The fact that deformability was aimed for, not homogenisation, is best illustrated by reference to the younger horizon 2 flat axes discussed below (see chapter 4.3): During this period there is a tendency for higher trace element contents, especially arsenic. Hence metalworkers might have opted for a homogenisation to slightly improve workability. Instead, there are only few axes in the fully homogenised state, and residual coring is the rule. Heat was applied during working with the softening in mind, which we now know to be the result of recrystallisation.

By contrast, most horizon 1 flat axes have a fully homogenised microstructure (figs. 4.5 and 4.6 M6, M11/12). Trace element contents are typically rather low in this group (fig. 4.7). Yet, there are some pieces with residual coring, which show that even at trace element contents well below 1 % the dendritic as-cast microstructure initially was slightly cored (e. g. sample nos. 92 and 122 with 0.2 % and 1 % trace elements respectively). Upon subsequent working these inhomogenities were removed in the majority of horizon 1 flat axes, which implies a rather high intensity of heating beyond temperatures and duration necessary for a mere recrystallisation. An effect of the resulting homogenisation on workability would have been even less marked than in the younger horizon 2 axes. It is unlikely, therefore, that homogenisation was deliberately aimed for by the heat treatment, let alone that homogenisation was conceived of as a separate production step.

Instead, it has been argued above that the procedure encountered is best interpreted as an intense 'warm hammering' or hot work of some length to compensate for a loss of ductility caused by the presence of the so-called ($Cu+Cu_2O$)-eutectic (see chapter 3.5). The oxide inclusions impeded the movement of 'defects' through the crystal matrix upon cold work, and instead metalworkers took to hot work, which avoids this problem by the continuous formation of new grains, to achieve whatever deformation was required to finish the object in question. It has already been mentioned, that cold work interrupted by repeated annealing and hot work in this definition should not in practical terms be conceived of as processes very far apart. But unlike the younger flat axes of horizon 2 (see below), in virtually none of the horizon 1 pieces is there evidence of further (final) deformation upon cooling (fig. 4.6 M10 and M16; see above for the one exception, sample no. 55). This finding clearly sets both traditions of forging apart. In horizon 1 – both for the shaft-hole axes and the flat axes – there is an emphasis on shaping at high temperatures and prolonged heating. This was almost completely replaced later by an approach to forging that involved a separate

production step of final cold hammering with an increase in hardness in mind (see chapter 4.3).

Instead, both horizon 1 shaft-hole implements and flat axes relied on the additional hardness provided by the ($Cu+Cu_2O$)-eutectic. We have to return to symbolic aspects of copper implements versus their potential for practical use below (see chapter 5.1). But, like the shaft-hole axes, in quite a number of horizon 1 flat axes there is microstructural evidence of use (fig. 4.6 M17). This typically takes the form of some rather weak deformation at the cutting edge and along the outer surface of the samples, which is in fact not easily distinguished from superficial changes in the microstructure induced by surface finishing. But it is quite obvious that flat axes apart from more symbolic uses were also (occasionally) involved in practical activities. Frequent re-sharpening of these rather soft copper implements would have been required for any prolonged life as tools or implements (Kienlin/Ottaway 1998). Certainly, they were not a clear alternative to contemporaneous stone tools in the same way that is true for the much later Early Bronze Age axes, which were heavily cold worked and consist of fahlore copper or tin bronze (see chapter 7; Kienlin 2008a). Still, use occurred, and it is likely that our data is biased towards evidence of rather mild use wear, while axes that had suffered heavier damage were re-cast.

Hence, for both symbolic uses (such as weapons in ritualised aggression beyond mere display) and practical activities, an increase in hardness would have been desirable to values above that of pure undeformed copper (around 50 HV) and negligible solid solution hardening due to low trace element contents (Northover 1989; Budd/Ottaway 1991; Lechtman 1996; Kienlin 2008a, 263–264 figs. 54 and 55). Like the contemporaneous shaft-hole axes this increase was achieved in consequence of 'shortcomings' in casting technique. For horizon 1 flat axes, too, can be shown to be harder than might be expected from their microstructure (recrystallised and without cold work) and composition alone (copper with rarely more than 1 % of trace elements; see fig. 4.7). With only five axes containing oxide particles to 15 pieces with the ($Cu+Cu_2O$)-eutectic, the latter oxide type is by far predominant among horizon 1 flat axes, and its presence clearly added to the total hardness of the axes in question (figs. 4.5, 4.6 M3 and 4.7).

An example is provided by sample nos. 49 and 121: both axes consist of relatively pure copper (0.4 % and 1 % trace elements respectively) without any deformation. Yet their hardness is at 76.9 HV/74.2 HV (point 1/3) and 74.8 HV/79.8 HV respectively. Both samples have consistent readings on points 1 and 3 (cutting edge/back part of the sample), which confirm that no deformation due to surface finish or use is involved. Instead their hardness values are clearly influenced by the hard and brittle ($Cu+Cu_2O$)-eutectic. It must be borne in mind that hardness is also dependent on other factors such as grain size, and the micro-hardness test (HV0.1) used is sensitive to minor differences in composition, pores and grain boundaries. Hence this data must not be used to postulate a linear relationship of hardness and the amount of the eutectic present. Still, it is remarkable that the highest hardness of 90 HV/92.8 HV in this group is reached by sample no. 109 which also has the highest oxide content of 3.95 % (figs. 4.6 M2 and 4.7).

In most flat axes of horizon 1, therefore, there is additional hardness induced by the presence of copper oxide inclusions. Its precise contribution to the total hardness, however, in many cases is difficult to determine since surface finish and/or initial use will also contribute to the final hardness level (see also chapters 3.2 and 3.3). In sample no. 108, for example, with a reading of 103.2 HV at point 1 (= tip of sample) it is quite obvious that hardness at the cutting edge was affected by deformation during use (i. e. the localised occurrence of deformed twins and some strain lines; see fig. 4.6 M17). In fact some millimeters back at point 3 in a sample area unaffected by use wear hardness declines to 83.2 HV. This latter value is still too high for pure undeformed copper (see above) and points to the additional influence of oxide inclusions on the hardness of this axe. Figures 4.6 and 4.7 show that this effect was in operation in a significant number of horizon 1 flat axes. For many pieces with some slightly deformed twins in their outward microstructure, due to surface finish and use, tend to have somewhat higher hardness values than those without any deformation – unused and with a method of surface finish which did not affect their microstructure.

Deliberate cold work, on the other hand, conceived of as a final production step to increase hardness is absent. The total reduction in thickness estimated for figure 4.6 was achieved by hot work only (see above). In this process oxide inclusions were deformed from their original shape, and porosity stemming from the casting process was largely or in part removed (fig. 4.6 M1 and M18). At least along their cutting edge and blade the axes obtained a rather dense microstructure. Based on deformed oxide inclusions and porosity for a number of samples a total reduction in thickness can be inferred that remained (well) below 50 %. Others had received a working in the 50 % range, but only rarely there are signs of heavier working above this value (figs. 4.5 and 4.6 M20). As mentioned earlier, it was possible to cast close to the final shape required, and working served to finish the axes only. However, this should not mislead us to underestimate the effort involved in this working and therefore the corresponding appreciation of these axes. A comparable reduction in thickness was found in many hammer axes examined, and among the axe-adzes, too, there is only a minority of pieces with a total reduction in thickness well above 50 % (see chapters 3.2 and 3.3). What variation there is most likely refers to the relative 'success' of specific casting events, and/or to individual decisions on how much work to spend on a deficient as-cast object instead of re-casting.

Copper oxide, most often in the form of the ($Cu+Cu_2O$)-eutectic, is present in all horizon 1 flat axes examined in variable amounts from 1.02 % of sample area in sample no. 108 to 7.51 % in sample no. 140 (fig. 4.6 M2/3). The mean

value is at 2.97 %, i. e. well above both contemporaneous hammer axes (1.84 %) and axe-adzes examined (1.7 %). This difference becomes even more marked when looking at the actual distribution. In the hammer axe group there was only one outlier, sample no. 176 with 7.56 % oxides, and in the axe-adze group with a maximum value of 3.69 % in sample no. 105-1 there was no piece in the above 4 % oxide range at all (see chapters 3.2 and 3.3). By contrast in the flat axe group there are four samples well above 4 % (sample nos. 86 [7.22 %], 120 [5.13 %], 140 [7.51 %] and 156 [6.06 %]) and another one at 3.95 % (sample no. 109). Clearly, these pieces do not represent the norm, and they are well separated from the bulk of flat axe samples clustering between roughly 1 % and 3 %. But these values tend to be higher, and in particular there is no equivalent to the significant number of both hammer axes and axe-adzes clustering more or less clearly in the below 2% range of oxide contents (compare figs. 3.11 and 3.16).

While there is significant overlap, the flat axes in general seem to indicate lower control over and/or attention paid to oxygen pick-up during melting and casting (in practical terms, for example, care given to avoid contact with air upon melting). However, this should not be translated into different workshops producing 'high' quality shaft-hole implements and such with lower competence in charge of the production of day-to-day 'poor' quality flat axes. Most oxide contents observed in flat axes may also occur in individual shaft-hole axes, and not even sample nos. 86, 120, 140 and 156, which are particularly high in oxides, were excluded from further working but received the standard finish by hot working (fig. 4.6 M10). The conclusion drawn above in chapters 3.2 and 3.3 is confirmed that if these differences were noticed at all, a much higher oxygen pick-up was acceptable than we tend to assume. Unlike modern practice high oxide contents (in prehistoric terms e. g. a specific way of handling) were not automatically thought deleterious for casting and subsequent working (see above for influence of oxides on hardness). The number of samples available is rather small for such conclusions but the data might suggest, that more flat axes were produced in a specific 'suboptimal' or 'careless' way, and/or more of these escaped immediate re-casting than was the case with contemporaneous shaft-hole implements. In the above sense this is not a statement on different 'quality' or 'compentence'. But this finding might reflect varying degrees of attention paid and emphasis placed on the production of both groups of implements (for further discussion see chapter 5.1).

4.3 Transformations: The Metallographic Evidence of Horizon 2 Flat Axes

With the horizon 2 axes discussion moves on into a later phase of the Eneolithic/Copper Age, and there are significant changes to the *chaîne opératoire* of casting and working copper implements. The previous emphasis on shaping at high temperatures shifts in favour of a cyclical approach of cold work followed by annealing and final cold hammering. In a sense this change may be taken to represent a return to earlier practices involved in the working of native copper. The situation is more complex, however, since not only long-standing practice is revived, but modifications in hammering and forging (cold work both with shape and mechanical properties in mind) are closely linked to changes in casting technique from horizon 1 to horizon 2 (see below). Questions arise that concern the interrelationship of both developments. Could forging just revert to exploiting knowledge of traditional cold work that had always been retained; was this approach an obvious technological choice and option consciously taken once required? Or did 'traditional' practice already mean something different, i. e. hot work, and did the return to cold work require a renegotiation of metallurgical knowledge? How then does this relate to parallel changes in casting technique? Were they just an epi-phenomenon, or were they in fact the reason why forging had to be adapted? Finally, accompanying this development there is a move away from massive shaft-hole implements. We have to ask, therefore, how technological change relates to the wider domain of metallurgy in society? What were the effects of changing demands and conceptions on the appropriate use of metal and the shape and function material culture should take?

To start with an outline of the production processes involved, all horizon 2 flat axes examined contain oxide inclusions (figs. 4.9 and 4.10 M2/3), and in some pieces there is (dendritic) residual coring (figs. 4.9 and 4.10 M6; see also the corresponding tables in appendix II). Oxygen pick-up occurred while the copper was molten as well as upon pouring into the mould. After solidification there was a dendritic as-cast microstructure with irregularly formed, cored casting grains. Both features, oxides and residual coring, provide evidence of casting as the first step of production. This finding is in good accordance with both horizon 1 shaft-hole axes and flat axes (see above), but it is in no way self-evident in a wider perspective; mind the North American tradition of directly working native copper into a variety of artefact types without prior casting (Ehrhardt 2009). Technology has got 'style', and casting, although from a modern perspective easily be taken for granted, is the first step of a specific central and south-eastern European *chaîne opératoire* with a remarkable stability of practice throughout the Eneolithic/Copper Age period as well as into the Bronze Age. These are technological choices taken by metalworkers operating within a specific technological and cultural tradition. Their actions must not be subsumed under modern notions and knowledge on how to proceed 'best' in accordance with the material properties and the requirements of shaping metal artefacts.

The same is true for the application of heat during the subsequent production process and for the practice of forging; this provides an excellent example of such a historically specific trajectory in central and south-eastern European Eneolithic/Copper Age metalworking. All horizon 2 axes have a fully recrystallised microstructure (figs. 4.9 and 4.10 M8) and in all samples there is evidence of twinning with twin bands typically visible in most grains

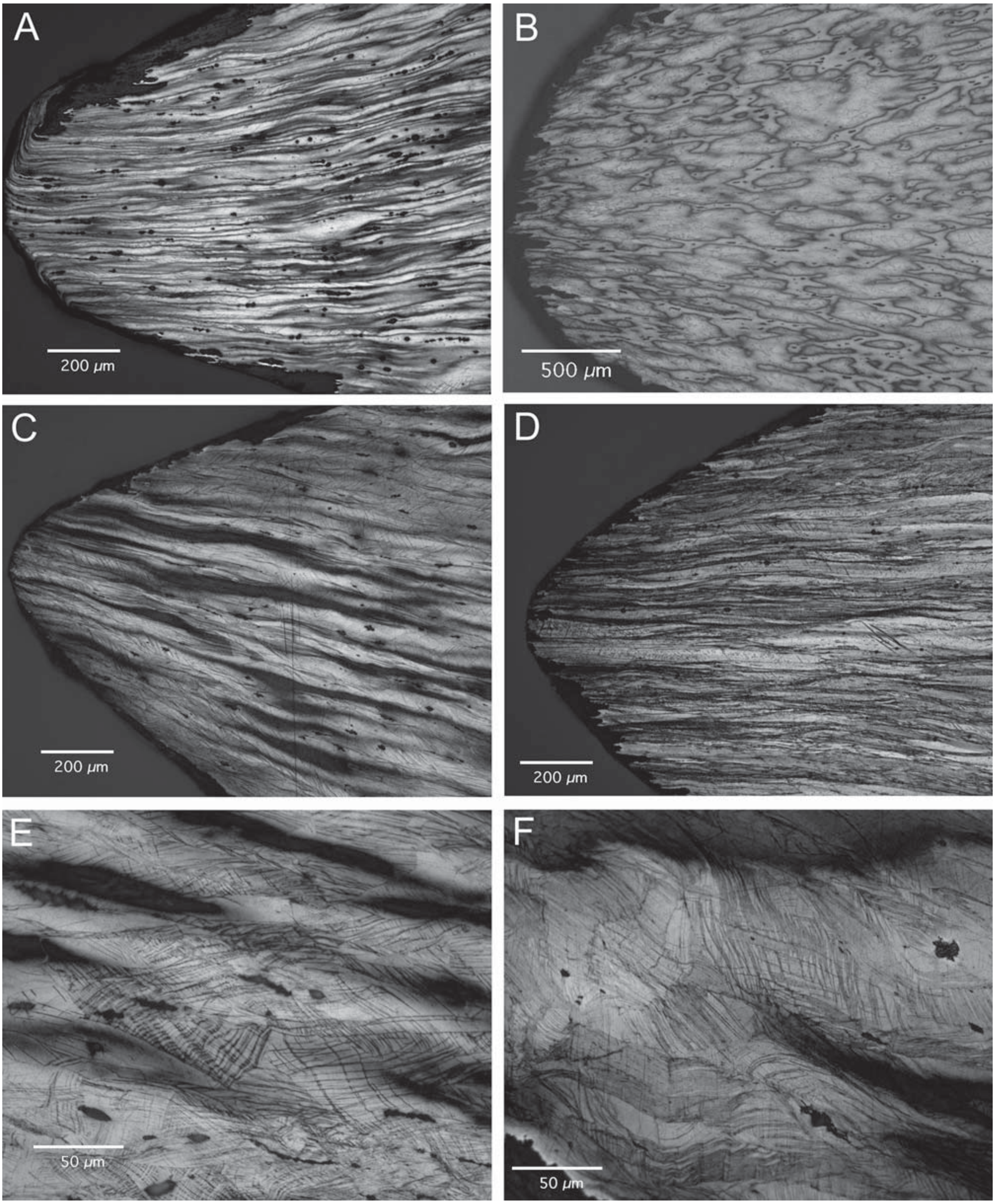


Fig. 4.9: Characteristic microstructures of Eneolithic/Copper Age horizon 2 flat axes examined for this study (A: sample no. 112 [note the high total reduction in thickness as indicated by the heavily deformed inhomogeneities]; B: sample no. 99 [note the limited total reduction in thickness as indicated by the considerably less deformed inhomogeneities]; C: sample no. 136 [note the heavily deformed grains due to strong final cold work]; D: sample no. 143 [note the heavily deformed grains due to strong final cold work]; E: sample no. 56 [note the strain lines indicative of final cold work]; F: sample no. 142 [note the strain lines indicative of final cold work]).

Sample no.	Porosity, phases and inhomogeneities						Production steps						Final cold work					Total working		
	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20
Eneolithic/Copper Age flat axes, horizon 2 (type)																				
56 (Vrádište)	(x)	8,92%	b	x	0	xx	0	xx	x	xx	0	0	x	x	xx	30-35%	-	x	x	~50%
74 (Vrádište)	0	0,46%	(b)	0	0	xx	0	xx	x	xx	0	0	0	x	xx	20-30%	0	-	x	<50%
76 (Altheim)	x	0,6%	(a)	0	0	0	0	xx	xx	x	x	x	0	0	0	0%	0	(x)	-	-
81 (Altheim)	(x)	1,89%	b	x?	0	xx	0	xx	x	xx	0	0	x	x	(xx)	30-35%	0	x	x	~50%
89 (Vinča)	0	4,38%	b	x?	0	(x)	0	xx	xx	xx?	(x)	(x)	0	(x)	x?	10-20%?	xx	x	(x)	-
90 (Vinča)	(x)	2,5%	b	x	0	(xx)	0	xx	x	xx	(x)	(x)	0	x	x	10-20%	xx	x	xx	>50%
95 (Vinča)	0	1,75%	b	x?	0	xx	0	xx	xx	xx?	0	0	0	(x)	0	10-20%?	0	0	(x)	<<50%
97 (Vinča)	0	2,66%	a/b	0	0	(xx)	0	xx	x	xx	(x)	(x)	(x)	x	0	~30%	0	(x)	x	~50%
99 (Vinča)	(x)	0,65%	b	x?	0	xx	0	xx	x	xx	0	0	(x)	x	(xx)	~30%	0	0	(x)	<50%?
112 (Vinča)	0	1,81%	b	0	0	xx	0	xx	x	xx	0	0	x	x	xx	35-40%	x	x	xx	70-80%
130 (Altheim)	0	4,05%	a	0	0	x	0	xx	x	xx	(x)	(x)	x	x	xx?	~40%	(x)	x	xx	70-80%
134 (Altheim)	(x)	2,08%	b	0	0	0	0	xx	xx	xx?	x	x	0	x	0	~20%?	0	-	-	-
136 (Altheim)	0	2,48%	b	0	0	xx	0	xx	x	xx	0	0	xx	xx	xx	45-50%	0	x	xx	70-80%
142 (Altheim)	(x)	0,59%	b	0	0	xx	0	xx	x	xx	0	0	x	x	xx	35-40%	x?	(x)	x	>>50%
143 (Altheim)	0	0,54%	b	0	0	x	0	xx	x	xx	(x)	x	xx	xx	xx	45-50%	0	x	xx	70-80%
147 (Altheim)	0	1,13%	a	x?	0	(x)	0	xx	(xx)	xx?	x	x	0	x	(x)	20-30%?	xx	x	x	~50%
154 (Vrádište)	(x)	1,49%	a	x?	0	(x)	0	xx	xx	x	x	x	0	0	0	0%	x?	(x)	-	-
155 (Altheim)	x	0,77%	b	0	0	(x)	0	xx	(x)	x?	x	x	0	0	x?	0%?	x?	-	-	-
207 (Altheim)	0	(xx)	a	x?	0	0	0	xx	xx	x?	x	x	0	x	0	10-20%?	x?	x	-	-
504003 (Altheim)	(x)	x	b	0	0	xx	0	xx	xx	xx	(x)	(x)	(x)	x	(x)	~30%	0	(x)	x	-
504401 (Altheim)	(x)	x	b	0	0	xx	0	xx	(xx)	xx	0	0	xx	xx	(x)	>50%	0	xx	xx	>>50%
504403 (Altheim)	0	1,09%	b	0	0	x	0	xx	x	x	x	x	0	0	x?	0%?	x	0	0	-
504404 (Altheim)	(x)	0,43%	b	0	0	(xx)	0	xx	xx	xx	(x)	(x)	(x)	x	xx	20-30%	x	x	(xx)	>50%
504405 (Altheim)	0	1,18%	b	0	0	x	0	xx	(xx)	xx	x	x	x	x	(x)	35-40%	0	x	x	-
504406 (Altheim)	0	2,3%	a/b	x?	0	x	0	xx	(xx)	xx	x	x	x	x	0	35-40%	0	(x)	(x)	-
504407 (Altheim)	(x)	0,92%	a/b	x?	0	(x)	0	xx	xx	x	x	x	0	(x)	0	0%?	0	0	0	-
504501 (Altheim)	(x)	0,62%	b	0	0	x	0	xx	x	xx	x	x	x	x	0	35-40%	x	0	x	-
504502 (Altheim)	(x)	0,57%	b	0	0	x	0	xx	x	xx	(x)	(x)	x	x	(x)	35-40%	0	(x)	x	-

Fig. 4.10: Microstructural features of the Eneolithic/Copper Age horizon 2 flat axes examined for this study (plus a series of previously examined Altheim type axes with sample nos. 504003 to 504502 from Kienlin 2008a, 107 fig. 35). M1: porosity (0 = none/hardly any; x = occasionally; xx = frequent) – M2: oxides (% of sample area) – M3: kind of oxides (a = [Cu+Cu$_2$O]-eutectic; b = particles) – M4: influence of oxides on hardness (0 = none; x = yes/assumed) – M5: further phases (0 = none/hardly any; x = present) – M6: coring in copper matrix (0 = none/hardly any; x = weak

residual coring; xx = heavily cored) – M7: casting grains (0 = none; x = present) – M8: recrystallisation (0 = none; x = partial; xx = complete) – M9: annealing twins (0 = none; x = frequent; xx = in most/all grains of sample area) – M10: production steps after casting (0 = none; x = as-cast, cold worked, or: cold worked, annealed, or: hot worked; xx = cold worked, annealed, cold worked, or: hot worked, final cold work) – M11: homogenisation (0 = none; x = partial; xx = complete) – M12: intensity of annealing (0 = equi-axed grains; x: equi-axed grains, partly homogenised; xx: equi-axed grains, homogenised) – M13: deformation of grains (0 = none; x = moderate; xx = heavily deformed) – M14: deformation of twins (0 = none; x = moderate; xx = heavily deformed) – M15: strain lines (0 = none; x = one system; xx = duplex slip) – M16: strength of final cold work (% reduction in thickness, close to the cutting edge/tip of the sample) – M17: wear traces (0 = none; x = additional deformation at the cutting edge due to moderate use; xx = tip of the sample heavily deformed due to heavy use) – M18: deformation/breakage of porosity/oxides (0 = none; x = moderate; xx = heavily deformed) – M19: deformation of coring (0 = none; x = moderate; xx = heavily deformed) – M20: estimated total reduction in thickness (% reduction in thickness, close to the cutting edge/tip of the sample).

throughout the whole sample area (figs. 4.9 and 4.10 M9; the only exception is sample no. 155, see below). A heat treatment was applied of sufficient intensity to erase the original casting grains and to allow the growth of new equi-axed grains with straight grain boundaries. Again, this cannot be taken for granted with the example of the Iberian Peninsula in mind (see chapter 3.5 and fig. 3.22; Rovira Llorens/Gómez Ramos 2003). Either while the object was hot or prior to the heat treatment the axes were hammered, in the first instance to give them their final shape after casting. Most likely casting seams were removed along with any surface defects that remained from the casting process. The blade was given its final outline and the cutting edge was sharpened. Given that the axes were cast close to their final shape (see below), all of these operations may have been done by grinding and polishing in a lithic tradition. In fact these techniques were clearly applied right at the end of the production sequence in order to achieve a good surface finish (see above in chapters 3.2 and 3.3 for the influence of grinding etc. on the microstructures of horizon 1 axes not otherwise cold worked in the final step). Hence, forging as such must not be taken for granted, for example note the different approaches to the production of copper ornaments by forging at the beginning of the Early Bronze Age in the north alpine region, followed somewhat later by an emphasis on casting under Únětice influence (see chapters 6 and 7).

If hammering as-cast objects into their final shape is subject to technological choice, forging as a shaping operation may be seen as another element of a specific Eneolithic/Copper Age metalworking tradition in central and south-eastern Europe. More importantly, however, this was an element, that was subject to historically specific modifications through time. We have seen above that both horizon 1 shaft-hole axes and flat axes were worked at high temperatures (fig. 4.11), most likely in consequence of the presence of a specific oxide type, the ($Cu+Cu_2O$)-eutectic, that reduced deformability but at the same time provided additional hardness to the implements in question. Working at high temperatures – be it in the sense of proper hot work or persistantly repeated 'annealing' steps – was conceived of as a shaping operation, but there was no step of final cold work carried out. Working/shaping and mechanical properties were conceptually set apart, with the latter possibly linked to the handling of the casting process (in modern terms we know that this determined the amount and type of the eutectic present after casting). Of course, this hardness may not have been conceived of as prone to manipulation or thought worth of such an attempt at all.

Now, in horizon 2 most axes examined show evidence of final cold work (figs. 4.9 and 4.10 M13–16; for more detailed discussion see below), and there still is substantial coring in many of them (fig. 4.10 M6), which points towards a heat treatment of limited overall intensity. Most likely this operation was perceived of (and practised) as a separate production step designed to restore deformability after previous cold work. Excessively lengthy annealing times or extreme temperatures were avoided perhaps as

they are fuel-consuming and may cause deterioration of mechanical properties. The procedure encountered is best interpreted as a cyclical working (fig. 4.11), with an initial cold work to compensate for any defects that remained after casting and/or give the axe its final outline.

Subsequent annealing may then have had a twofold aim. If a stronger deformation was required to finish an axe than was easily achieved in one go annealing was carried out to restore deformability for further working. Indeed there is evidence from both the Eneolithic/Copper Age horizon 2 and the Bronze Age that annealing took place rather early (Junk 2003, 170; Kienlin 2008a, 173), possibly to facilitate further working/shaping, so this motivation might have been rather common. Alternatively, or rather additionally, if working had initially been carried out with shape in mind the deformation that was achieved may have been relatively uncontrolled and/or unevenly distributed. Annealing might then have been carried out to 'reset' mechanical properties for final cold work in order to add to the strength and durability of the cutting edge in a defined way. Again, support for this interpretation can be drawn from both Eneolithic/Copper Age data (horizon 2; see below) as well as from the examination of Early Bronze Age axes (Kienlin 2008a): The approach to final cold work is different in both periods, and in addition during the Early Bronze Age various regional traditions can be discerned. However, in both periods it is obvious that metalworkers were actively interested in the hardness of their axes. Some broadly defined cold work of medium strength was aimed for in order to increase their durability. On the other hand, excessively heavy deformation without intermediate annealing, such as may result from shaping operations directly followed by final cold work, was avoided, since it is of no further use in terms of hardness (see below) or may eventually cause brittleness.

Out of 28 flat axes which were examined from horizon 2, only five do not show any sign of deliberate final cold work (figs. 4.10 M16 and 4.12). In the microstructures of sample nos. 76 and 154 there is neither evidence of deformed grains nor are there any deformed twins or strain lines. Hardness readings of 52.7 HV/47.2 HV (point 1/3) and 50.5 HV/44.9 HV respectively, which match experimental data of comparable low percent arsenical copper (see the graphs for 1 % and 2 % arsenic in Kienlin 2008a, 263–264 figs. 54 and 55), confirm that no deformation took place in the final step (fig. 4.13). Twinning indicates that prior to annealing some forging was done. But in sample no. 76, in particular, a high degree of porosity remains, while the surface of the axe with sample no. 154 still shows unevenness that may go back to the casting mould. Both axes give the impression of being essentially unfinished in terms of horizon 2 standards of a cyclical working.

In principle what restricted deformation took place might have been done in the older horizon 1 style by hot work, and in fact both pieces in question are among the smaller group of horizon 2 axes that contain the (Cu+Cu_2O)-eutectic (more marked so in sample no. 154; see fig. 4.10 M2/3). However, with a relatively small amount of oxide present (sample no. 76: 0.6 % of sample area; sample no. 154: 1.49 %) its influence on hardness was restricted. As mentioned earlier, microstructural evidence should not be stretched to date individual objects. It is tempting, of course, to see these pieces as an extension of an earlier horizon 1 tradition of working copper implements. But at least in sample no. 154 there is still residual coring that points towards a limited intensity of heat treatment (unlike horizon 1; see above), and most likely pieces like sample nos. 76 and 154 just represent the variation to be expected in the context of prehistoric/traditional metalworking. For some reason or other after some initial cold work and annealing this operation was not taken further to its proper end including cold work for hardness. Still, in sample no. 154 there may be some weak indication of short-term use; for a similar finding of an unfinished axe that went into use see sample no. 103 among the horizon 1 flat axes examined in chapter 4.2.

Much the same applies to sample nos. 155, 504403 and 504407, in which there is no evidence of final cold work either (figs. 4.10 and 4.13). In sample no. 155 annealing twins are restricted to the cutting edge and surface area of the sample indicating that prior (cold) work was only of very limited intensity. Some grains with strain lines right at the cutting edge are best interpreted as a result of physical use, which may also be seen in a decline of hardness readings from 79.2 HV at the tip of the sample affected by use (point 1 = cutting edge) to 50.5 HV in the back part of the sample (point 3). Sample no. 504403 has more frequent annealing twins throughout the whole sample area. Judging from residual coring and oxide inclusions, however, total reduction in thickness is limited. Despite a rather high hardness value of 65.5 HV at point 3 (core of the sample), only slightly below that on point 1 with 68.4 HV, the presence of some grains only with strain lines rather points to the effect of surface finish and/or use than to cold work proper as seen below in the majority of horizon 2 axes. Similarly, in sample no. 504407 there are only a few slightly deformed annealing twins indicative of weak superficial deformation. Prior to annealing, too, forging was of limited intensity since the dendritic patterning of residual coring and oxide inclusions are basically undeformed. With its blunt 'cutting edge' of about 2 mm thickness at the tip of the sample this axe was clearly unfinished. It illustrates the amount of work required to finish at least some of the worse moulding blanks in this group. For the reasons given, in figure 4.12 these axes are shown under the heading 'undeformed'. In figure 4.10 (M16) they carry the specification 0 %*?* to indicate that there are some slightly deformed twins or strain lines, but these features are thought unlikely to represent proper cold *work* in the sense of a separate (final) production step.

Another eight samples do not show the deformed grains indicative of a rather strong cold work, but there are deformed annealing twins and/or strain lines throughout the sample including its backward core (fig. 4.10 M16; sample nos. 74, 89, 90, 95, 134, 147, 207 and 504404). Two of

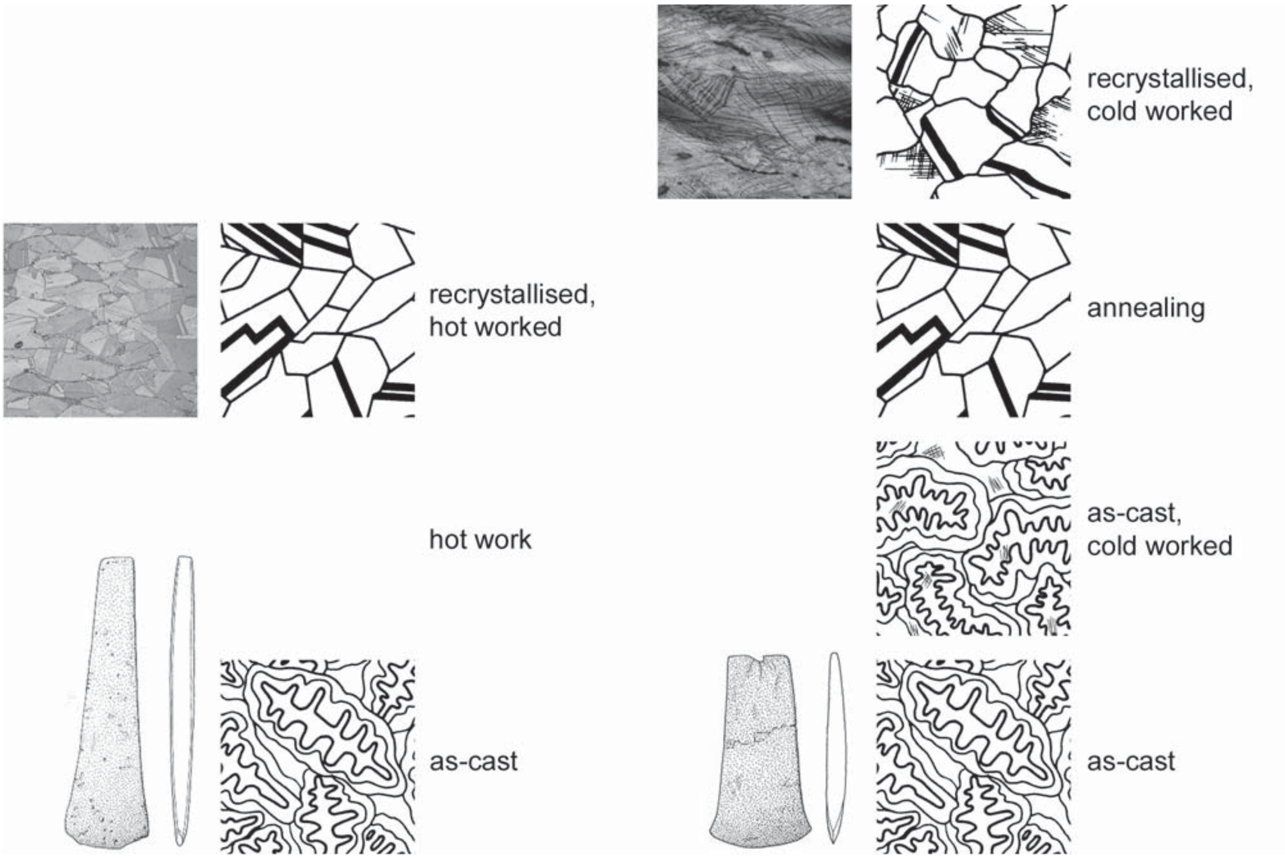


Fig. 4.11: Comparison of the suggested chaînes opératoires for the finishing of Eneolithic/Copper Age horizon 1 and horizon 2 flat axes.

these, sample nos. 89 and 90, show traces of use hardening in their microstructure close to the cutting edge, and the latter axe with sample no. 90 suffered quite substantial bending of a part of its blade upon prolonged use. In order to avoid such damage frequent re-sharpening would have been required, and most pieces surviving in the archaeological record do not show comparable evidence of such heavy damage. This is probably due to both more appropriate uses of these implements combined to frequent re-sharpening and the practice of recasting damaged implements into new ones. Sample no. 90 was taken from a less heavily damaged part of the cutting edge, and it is thought unlikely that the deformation observed in its core is an extension of use/damage that occurred right at the cutting edge. Rather, prior to use/damage there was some light final cold work that also affected the core of the sample and caused an increase in hardness to 95.8 HV at point 3 (fig. 4.13). The same applies to sample no. 89, where the zone affected by use wear is extending backwards from the tip of the sample (=cutting edge) for only about 300 µm. The hardness of this area is at 111.4 HV. Some lighter deformation in the core area which corresponds to a hardness of 76.6 HV points towards cold work in the final production step. In sample no. 95 there is no clearly recognisable use wear at all, and hardness values of 106.6 HV/78.2 HV (point 1/3) are most likely due to cold work. In sample no. 207 the presence of use wear is doubtful, and certainly it did not reach the core area. Hardness values of 114.7 HV at point 1 and 83.2 HV at point 3 reflect some mild cold work that also affected the core area.

In figure 4.10 M16 these axes carry the specification 10–20 %*?* in order to indicate that there might have been some influence of surface finish and/or use on the deformation observed. However, for the reasons given it is thought likely that there was some mild cold work in the given range that also affected the backward part of these samples. Another four samples, nos. 74, 134, 147 and 504404, were classified in the 20–30 % range (see appendix I; Northover 1989; 1996; Buchwald/Leisner 1990; Scott 1991; Wang/Ottaway 2004; Kienlin 2008a, 43–75). In their case the higher frequency of deformed twins and/or strain lines throughout the sample area leaves little doubt of some – still rather mild – cold work carried out in the final step. In sample nos. 147 and 504404 there is additional use wear at the cutting edge (hence 20–30 %*?* for no. 147 in fig. 4.10 M16). But hardness values at about 100 HV even in the core area of three of these samples clearly indicate that cold work took place that also affected the backward part of the blade (fig. 4.13, HV point 3; exception: sample no. 504404 with 89.2 HV). In figure 4.12 this group of axes is shown under the heading of “twins deformed/strain lines [*use wear/cold work*]”. But from the above discussion of the axes in question and from their technological context (i. e. what appears to be the ‘standard’ cyclical working

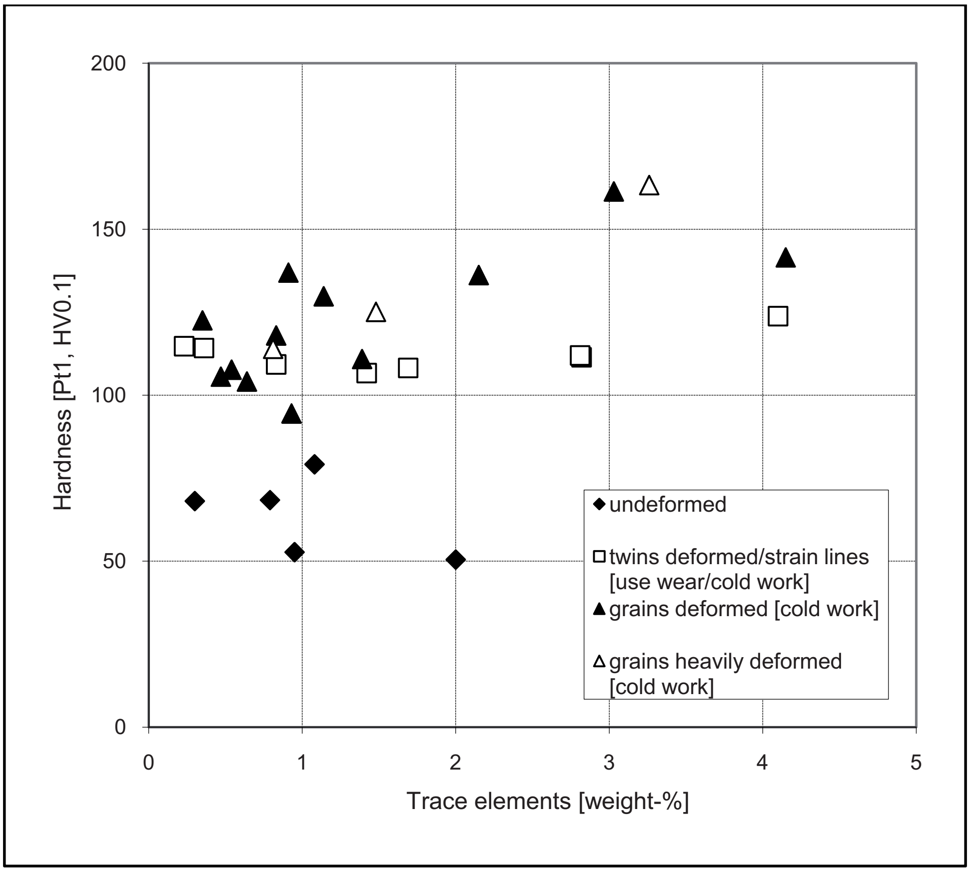


Fig. 4.12: The hardness of the Eneolithic/Copper Age horizon 2 flat axes, depending on composition and cold work (data of this study plus a series of previously examined Altheim type axes from Kienlin 2008a, 107 fig. 35).

aimed at in horizon 2; see below) cold work is the preferred interpretation.

There is variation in the strength of final cold work in this group of horizon 2 axes, which may be expected in a context of non-verbal learning and the non-theoretical transmission of metallurgical knowledge in prehistoric society (see chapter 5.4). But there is also patterning to inform us on the reasons for forging and the knowledge of material properties gained by Eneolithic/Copper Age metalworkers. In the course of a fairly complex production process, which consisted of at least two phases of cold working, some axes reached a fairly high reduction in thickness (e. g. sample nos. 112 and 504401 with heavily deformed residual coring and oxide inclusions; fig. 4.10 M18–20). This can be interpreted as a sign that occasionally forging took place on a blade that still required considerable shaping after the casting process (see also sample no. 504407 discussed above). On the other hand, however, there are samples with a limited overall reduction in thickness (e. g. sample nos. 95 and 99; fig. 4.10 M18–20). At least in the production of these axes it was possible to cast close to the final shape required (see chapters 3.4 and 4.4). In addition, final cold work in this group was often stronger than the deformation achieved in the previous step. Rather than a mere shaping operation, therefore, an increase in hardness can be considered as motivation for, or at least a side-effect of, final cold work.

With regard to the axes discussed above, which were classified in the 10 % to 30 % deformation range, there remained some doubts on the (additional) influence surface finish and or/use had on their hardness. However, with deformation extending into the core of the samples it is quite obvious that a deliberate forging of the whole blade area took place. The increase in hardness achieved to values well above 100 HV hardly went unnoticed (fig. 4.12). It reflects a deliberate effort to improve the durability of these axes. Although their cold work is rather mild, it is strongly suggestive of affiliation to the same broad tradition of manipulating the mechanical properties of copper-based implements we see in the larger group of horizon 2 axes with deformed grains (fig. 4.9). This feature is indicative of a somewhat more substantial cold work with more or less heavily deformed grains at the cutting edge (fig. 4.10 M13) as well as deformed twins and/or strain lines throughout the backward part of the samples (fig. 4.10 M14–15). It is noteworthy, however, that usually there is only a moderate deformation of grains in the 30 % to 40 % deformation range (fig. 4.10 M16), while there are only three axes whose microstructure shows a more extreme elongation of grains indicative of a reduction in thickness beyond 45 % to 50 % (sample nos. 136, 143 and 504401). Forging did not, therefore, aim at the highest possible deformation that could be achieved with this ductile (arsenical) copper (fig. 4.14). The corresponding increase in hardness to about 100 HV to 150 HV (fig. 4.12; with a minimum value of

Sample no.	HV pt1	HV pt3	Cu	S	Sn	Pb	As	Sb	Ag	Ni	Co	Fe	Bi	Sum TE
Eneolithic/Copper Age flat axes, horizon 2														
56	141.5	109.8	95.9	-	0.6	-	3.5	-	-	-	-	-	-	4.1
74	111.9	107.2	97.2	-	-	-	2.6	0.2	-	-	-	-	-	2.8
76	52.7	47.2	99	-	0.2	-	-	-	0.4	0.2	-	0.2	-	1
81	122.5	110.9	99.6	-	-	-	0.4	-	-	-	-	-	-	0.4
89	111.4	76.6	97,2	-	-	-	0.8	1.7	-	-	-	0.3	-	2.8
90	108.2	95.8	98.4	-	-	-	0.9	-	-	0.6	-	0.1	-	1.6
95	106.6	78.2	98.6	-	-	-	1.4	-	-	-	-	-	-	1.4
97	104.1	98.5	99.4	-	-	-	0.6	-	-	-	-	-	-	0.6
99	129.8	109.2	98.9	0.1	-	-	1	-	-	-	-	-	-	1.1
112	161.4	131.2	97	-	-	-	3	-	-	-	-	-	-	3
130	136.9	108.2	99	-	-	0.3	-	-	0.2	0.3	-	0.2	-	1
134	109.2	100.8	99.1	-	-	-	-	0.4	0.3	-	-	0.2	-	0.9
136	163.3	110.9	96.7	-	-	-	2.9	-	-	0.2	0.2	-	-	3.3
142	136.2	113.1	97.9	-	-	-	1.9	-	0.2	-	-	-	-	2.1
143	125.1	111.9	98.5	-	0.6	-	0.6	-	-	0.3	-	-	-	1.5
147	114.2	98.5	99.6	-	-	-	-	-	0.4	-	-	-	-	0.4
154	50.5	44.9	98	-	1	-	-	0.2	0.4	-	-	0.4	-	2
155	79.2	50.5	98.9	-	-	0.5	-	-	0.6	-	-	-	-	1.1
207	114.7	83.2	99.8	-	-	-	-	-	0.2	-	-	-	-	0.2
504003	118	74.2	99.2	-	0.1	-	0.6	-	-	0.1	-	-	-	0.8
504401	114	93.2	99.2	-	-	-	0.6	-	0.2	-	-	-	-	0.8
504403	68.4	65.5	99.2	-	-	-	0.7	-	-	-	0.1	-	-	0.8
504404	123.8	89.2	95.9	-	-	0.3	3.5	-	0.2	-	-	-	-	4
504405	94.5	86.1	99.1	-	-	-	0.7	-	-	0.3	-	-	-	1
504406	105.6	81.5	99.5	-	-	-	0.5	-	-	-	-	-	-	0.5
504407	68.1	52	99.7	-	-	-	0.3	-	-	-	-	-	-	0.3
504501	107.7	79.2	99.5	-	-	-	0.4	-	-	-	-	0.1	-	0.5
504502	110.9	76.3	98.6	-	-	0.2	0.9	-	-	-	0.3	-	-	1.4

Fig. 4.13: Hardness and composition of the Eneolithic/Copper Age horizon 2 flat axes examined for this study (plus a series of previously examined Altheim type axes with sample nos. 504003 to 504502 from Kienlin 2008a, 107 fig. 35; Vickers microhardness HV0.1 at the tip of the sample [pt. 1 = cutting edge] and at the back of the sample [pt. 3 = core]; EDX analyses, weight-%, rounded to one decimal).

94.5 HV in sample 504405 and a maximum at 163.3 HV in sample no. 136) may substantially add to the durability of such implements, but it is also close the values obtained in the previous group by a weaker deformation only (see above; fig. 4.8). Both features in combination – the lack of extremely high deformation rates and comparable hardness values achieved – provide important information for characterising the approach to forging in horizon 2.

Looking at composition and strength of cold work it becomes apparent that there is no tendency towards more intense cold work with increasing trace element, namely arsenic content (figs. 4.12 and 4.14). Based on a much larger data set than hitherto available, P. Budd's (1991a, 106–107) conclusion from the examination of some Altheim axes is confirmed that the different work hardening properties of pure and arsenical copper were not recognised during the period in question. This contradicts modern expectations of the conversion of high arsenic contents into greater hardness. It is possible, however, to present a rather straightforward explanation of this finding by reference to the clustering in the broad 20 % to 40 % deformation range observed above. Experimental data show that with most copper-arsenic alloys the increase in hardness levels off at a reduction in thickness beyond 20 % to 30 % (e. g. Buchwald/Leisner 1990, 73 fig. 20; Northover 1989, 113–114 figs. 13.3, 13.4 and 13.5; Budd/Ottaway 1991, 140 figs. 4 and 5; Lechtman 1996, 488, 494–496 figs. 18, 19 and 20; Junk 2003, 156 fig. 7.26; Kienlin 2008a, 263–264 figs. 54 and 55). This is particularly marked for copper with 1 % arsenic, which rapidly reaches a hardness of around 110 HV at a reduction slightly above 20 %. Among the axes examined, therefore, we see a clustering around or slightly above the point at which there occurs a slowing down of further increase in hardness (fig. 4.15). The conspicuous absence of significantly higher rates of deformation reflects the empirically gained knowledge of a *point of diminishing returns* for the working of copper with low trace element contents (Kienlin/Bischoff/Opielka 2006; Kienlin 2008a, 106–111).

4.4 The Casting of Flat Axes: General Characteristics

Drawing on different aspects of the evidence available, both open moulds and (closed) two-piece moulds have been suggested for the axes in question. Their 'primitive' form, pieces with asymmetrical cross-section (adzes) and their early date are taken to imply the use of open moulds. Oxide inclusions and heavy forging are thought to support this assumption, and indeed there are a limited number of mould finds that seem to prove this line of argument (Novotná 1970, 18–19; Mayer 1977, 50, 57–58; Patay 1984, 13; Budd 1991a, 99; Žeravica 1993, 54; Magnusson Staaf 1996, 120). On the other hand, the number of moulds known is very small and hardly sufficient to establish a casting technique commonly used. Other authors, therefore, focus on the precision of the axes' outline and their cross-section to imply the use of closed two-piece moulds. Still others doubt that casting in open moulds is practicable and would have given satisfactory results at all (e. g. Sangmeister 1971, 123; Sangmeister/Strahm 1973, 202–203, 206–207; Dobeš 1989, 39).

The evidence is ambiguous, and even metallographic examinations do not provide a definite solution to this problem. P. Budd (1991a, 106) in his study on Altheim axes concluded that the appearance of oxide inclusions is a sign of casting in an open mould. In an earlier study on Eneolithic/Copper Age shaft-hole axes, oxides were found concentrated along the upper side of the axes which – presumably – was left uncovered during casting (Charles 1969, 40–41; see however discussion in chapter 3.4). Hence, there are two different lines of argument, and both of them – the presence of oxides as such and their distribution throughout the object – do not provide clear evidence of open mould casting. In the larger series of flat axes examined here there is no evidence of clustering along any one surface of these artefacts (see tables in appendix II). Clearly, larger samples are desirable to provide information on the distribution of oxides throughout the whole object. However, it is thought unlikely, that the oxides in their observed form and distribution indicate open mould casting. The appearance of oxide inclusions as such, on the other hand, are certainly not a sign of casting in an open mould as suggested by Budd (1991a). We have seen above that even with high oxygen contents, objects could be cast without any restriction on further processing and use (see also Northover 1989, 111–112). Their appearance does not, however, carry any implications on the use of *open* moulds. On the contrary, the presence of oxides may reflect a limited control over gas absorption during *different* steps of the melting and casting process, for instance in covering the crucible with a charcoal layer, the skill involved in the actual casting of the molten copper or varying cooling rates according to the mould material.

Similarly, there are some axes that reached a fairly high reduction in thickness (figs. 4.6 and 4.10; see chapters 4.2 and 4.3). This can be interpreted as indicating that forging took place on a blade that still required considerable shaping after the casting process (Budd 1991a, 106). On the other hand, however, there are samples with a limited overall reduction in thickness. It is doubtful whether this finding, contrary to Budd's claims, can be related to casting in an open mould. We may have to be careful here, since there are some variants of the implements in question that have an asymmetrical cross-section indicating use as an adze (e. g. type Szakálhát; Mayer 1977, 50; Patay 1984, 24–25; Žeravica 1993, 54–55). Some pieces of this kind were examined, and the oxides found to be evenly distributed throughout the sample (e. g. sample nos. 46, 108 and 130; Mayer 1977, 50 nos. 110 and 111; Říhovský 1992, 68 no. 117). In other cases this kind of tool with a plain surface (the upper side in casting, the lower side in use?) might have invited casting in an open mould. But, from a modern perspective at least, this choice of casting technique would have unnecessarily increased the amount of work required to prepare the as-cast object for use. The fact that there was choice, and closed moulds were known, at least during horizon 2, is proven by one of the Altheim

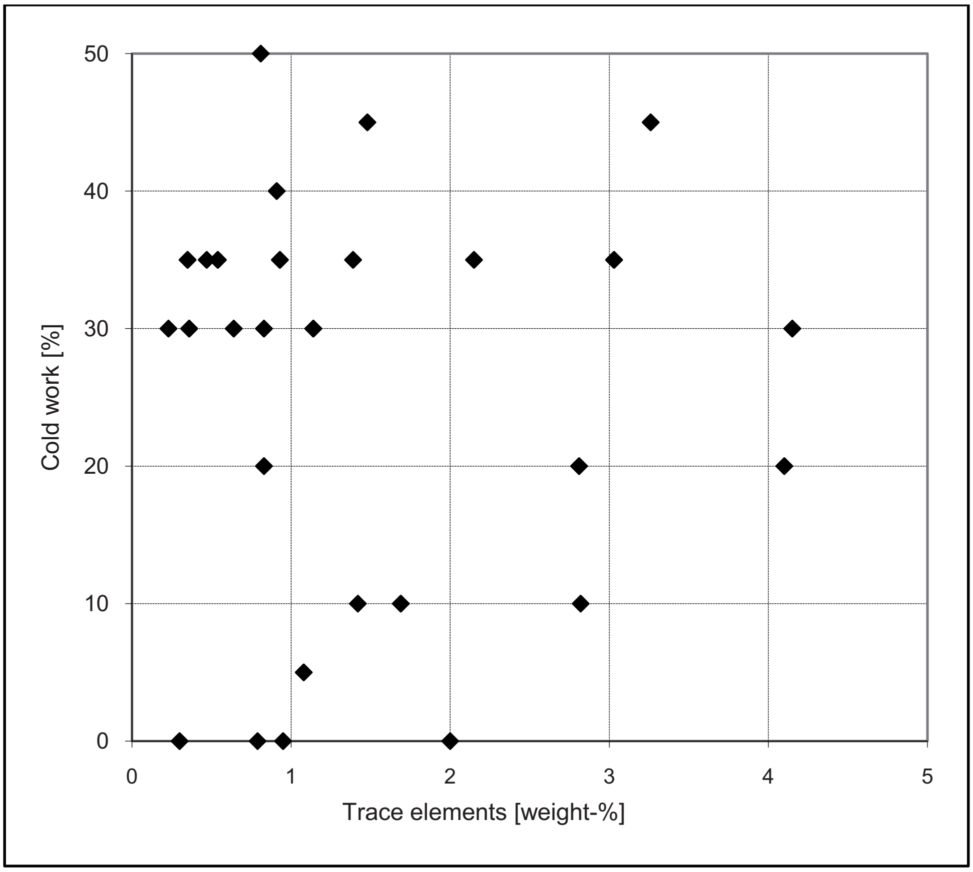


Fig. 4.14: Strength of final cold work in the group of Eneolithic/Copper Age horizon 2 flat axes (cold work: % reduction in thickness; note that to simplify this graph the broader ranges given in the text and fig. 4.10 M16 have been reduced to the lowest possible value respectively, e. g. an estimated deformation in the 20 % to 30 % range [i. e. twins deformed and strain lines] will appear on the 20 % line; data of this study plus a series of previously examined Altheim type axes from Kienlin 2008a, 107 fig. 35).

axes examined (sample no. 504501). A shrinkhole in the neck of this piece provides clear evidence that casting took place in an upstanding closed mould (fig. 4.16). Later on during the Early Bronze Age there is ample evidence of this casting method provided by metallographic analysis and the increased porosity in the neck of the axes shown by X-rays (see chapter 7; Kienlin 2008a, 132 fig. 38, 258 fig. 53).

Since there is only one (partly recrystallised) as-cast microstructure (sample no. 103, horizon 1; see chapter 4.2) it is impossible to determine the secondary dendrite armspacing that might help to determine the kind of moulding material used. It is only by reference to Early Bronze Age practice that (two-piece) sand moulds can also be suggested for this early period (see Junk 2003, 62–127, 170 and Kienlin 2008a, 255–262 for microstrutural evidence of Early Bronze Age use of sand moulds). Although archaeologically 'invisible' this casting method and moulding material clearly has to be taken into consideration. Experimental work shows the ease of this technique (Ottaway/Seibel 1998; Wang/Ottaway 2004).

4.5 Casting, Oxides and Compositional 'Determinism'

The majority of both shaft-hole axes and flat axes of the older Eneolithic/Copper Age horizon 1 defined for this study contain the ($Cu+Cu_2O$)-eutectic. It was shown above that this specific type of oxide inclusions reduced deformability and favoured shaping at high temperatures (hot work), but at the same time it provided additional hardness to the copper implements under study (see chapters 3.5 and 4.2). Horizon 2 flat axes, on the other hand, rarely show the ($Cu+Cu_2O$)-eutectic (fig. 4.17). Instead they contain distinct oxide particles that may be plastically deformed, and in fact forging in this group involved a cycle of cold work, annealing and renewed cold working (fig. 4.11).

In a long-term perspective, working native copper by hammering and annealing meant there was no casting process involved that may result in oxygen pick-up. Shaping was done by cold work, and what additional hardness was required had to be achieved by work hardening, thus encouraging a final cold work. When casting native copper or rather copper smelted from oxidic copper ores there was – initially – quite substantial oxygen pick-up, and the formation of the ($Cu+Cu_2O$)-eutectic increased hardness. It is this stage of development that our horizon 1 axes belong to. Their performance benefitted from actual 'shortcomings' in casting technique. Besides, surely, it was culture, through an overriding interest in the sheer size and weight of metal objects, which prevented attempts at cold working horizon 1 shaft-hole implements. There are traces of wear in the

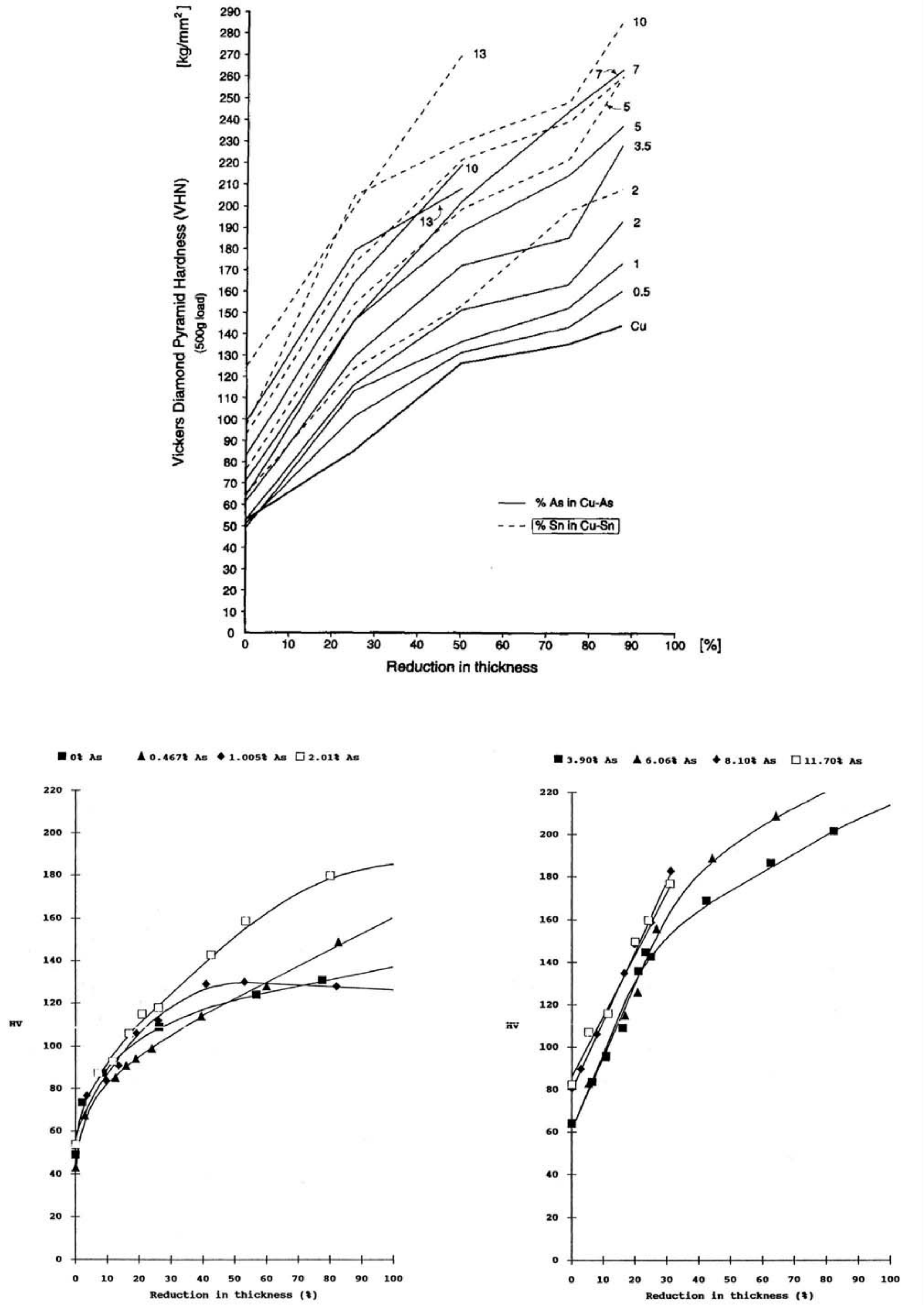


Fig. 4.15: The work hardening of arsenical copper and tin bronze, depending on composition and cold work – experimental data (after Lechtman 1996, 496 fig. 20 [above]; Budd/Ottaway 1991, 140 figs. 4 and 5 [below]).

microstructures, so they were not just intended for display, but they were certainly not up to cutting trees over an extended period of time. In any case their hardness – in part derived from oxide inclusions – was felt to meet the demands in use, most likely social in the widest sense, including conflict. Apparently, over the years social and cultural demands changed. Massive shaft-hole implements lost their attractiveness, and metallurgy followed by providing 'better' flat axes instead. With this horizon 2 there is a reversal of previous developments, a return to the older practice of cold working. This process coincides with somewhat higher trace element contents in some horizon 2 axes at least; the shift to so-called arsenical copper. We have to ask therefore what influence composition had on the changes observed from horizon 1 to horizon 2, or if the change in oxide type was a result of modifications in casting technique.

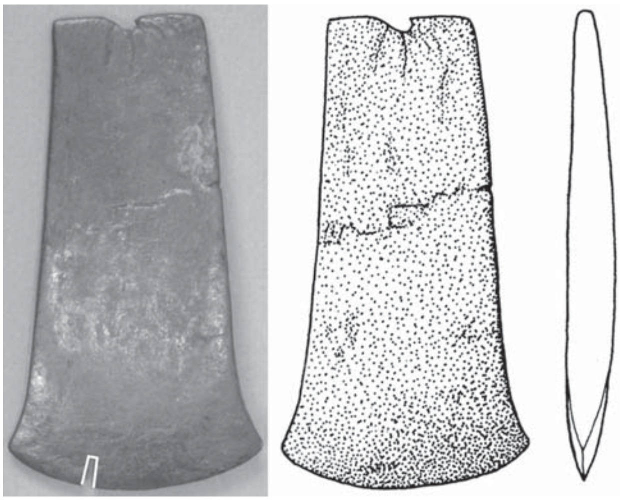


Fig. 4.16: Evidence of Eneolithic/Copper Age casting in upstanding closed two-piece moulds: shrinkage in the neck of an Altheim type axe (Kienlin 2008a, 773 tab. 149 [sample no. 504501]; Mayer 1977, 55 no. 141, tab. 11 no. 141).

Starting with a comparison of the flat axe data, it is obvious that horizon 1 axes with an average of 2.97 % contain a distinctly higher amount of oxide inclusions than those of horizon 2 with an average of 1.83 %. Arsenic, in particular, is thought to have a de-oxidising effect by forming insoluble oxides which are removed upon casting (e. g. Charles 1967, 21; Roberts/Thornton/Pigott 2009, 1015; cf. Ottaway 1994, 130). From figure 4.18, however, it is obvious that trace elements do not directly improve casting properties in this way. In both horizon 1 and 2 there is no apparent relation between trace element content and the frequency of oxide inclusions. In horizon 1 there are only two samples with trace element contents in excess of 2 % (sample nos. 86 and 140 with 3.5 % and 2.2 % TE respectively), and both pieces contain a distinctly high amount of oxide inclusions (7.22 % and 7.51 % of sample area; compare figs. 4.6 and 4.7). Similarly, in horizon 2 with a greater number of axes high in trace elements (up to slightly above 4 %) the amount of oxide present does not correlate with trace element contents either. The variability encountered is best illustrated by sample nos. 56 and 504404 with the highest trace element contents in horizon 2 (4.1 % and 4 %), which have widely different oxide contents of 8.92 % and 0.43 % of sample area respectively (see figs. 4.10 and 4.13). In the below 1 % concentration range of trace elements most horizon 2 axes contain less than 2 % of oxide inclusions, but there are exceptions, and in sample no. 130 at 1 % trace elements oxide is up to 4.05 % (fig. 4.18). Horizon 1 axes, on the other hand, in this concentration range often contain oxide inclusions well above 2 % of sample area. In chapter 3.3 some limitations on the interpretation of these findings were discussed. Certainly, all trace elements less noble than copper, depending on their relative affinities to oxygen, have a more or less strong de-oxidising effect. However, it is quite obvious that irrespective of the starting point of the system in terms of the original trace element contents and their relative amount removed during casting, the result is erratic. Even if metalworkers used copper containing generally high levels of trace elements it was possible to end up with a 'poor' result in terms of oxide inclusions. Equally, the other way round, using generally low trace element copper could result in cast objects that were low in oxides. It follows that it is not only the absolute amount of trace elements present (i. e. the copper chosen) that reduces oxide inclusions, but the handling of the molten copper prior to and during casting. Examples include the use of a charcoal layer to cover the crucible and care given during casting to minimize exposure of the molten copper to the air. It is in this respect that there is a difference between horizons, for horizon 2 axes tend to contain less oxide inclusions irrespective of composition. Quite obviously the handling of the casting process was different and probably more 'advanced' than with the earlier axes of horizon 1.

In terms of subsequent working we have seen above that the kind of oxide inclusions present is actually of greater importance than mere frequency. We have to ask, therefore, how the presence of a network consisting of the ($Cu+Cu_2O$)-eutectic as opposed to particles of copper oxide or mixed copper-arsenic oxides relates to composition. At first view, from figure 4.18 one gets the impression that the ($Cu+Cu_2O$)-eutectic is more likely to occur in axes with low trace element contents. Yet, in both horizons there are exceptions to this rule with trace element contents up to around 2 % (horizon 1: sample nos. 140 [2.2 %] and 157 [1.8 %]; horizon 2: sample no. 154 [2 %]). Vice versa the same holds true for distinct oxide particles. The few horizon 1 axes with this oxide type cluster around a trace element content of 1 %, which is rather high for this group of axes (e. g. sample nos. 55 [1 %] and 103 [1 %], in addition sample no. 86 at above 3 % TE). The axes of horizon 2, however, show that this oxide type occurs alongside the ($Cu+Cu_2O$)-eutectic down to trace element contents as low as 0.4 % and 0.5 % in sample nos. 81 and 504501 respectively (see figs. 4.6, 4.7, 4.10 and 4.13). For this reason composition may have an important part to play in the formation of the oxide types discussed but procedure must not be neglected either. Most likely the different frequency of both oxide types in horizons 1 and 2 are the

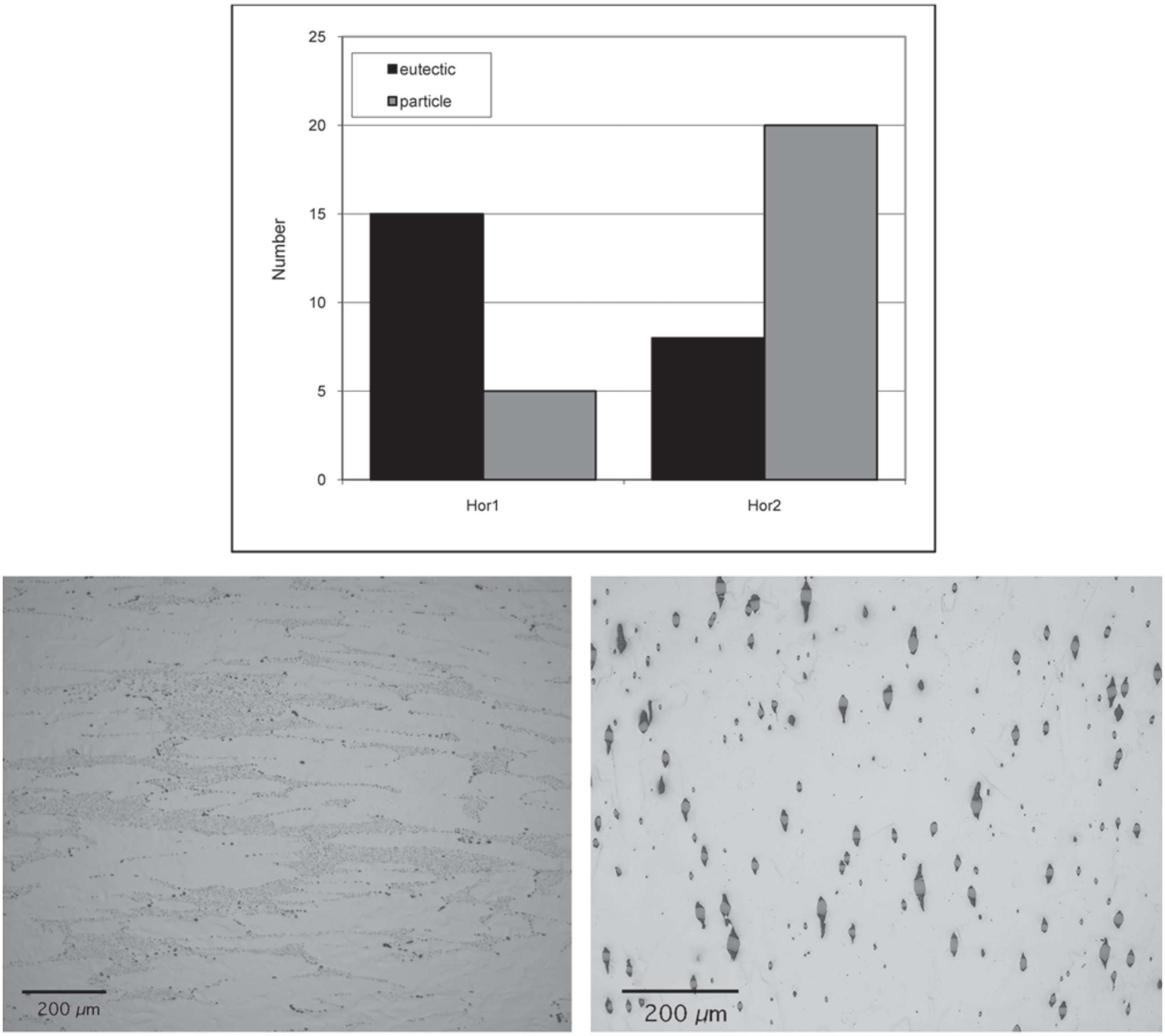
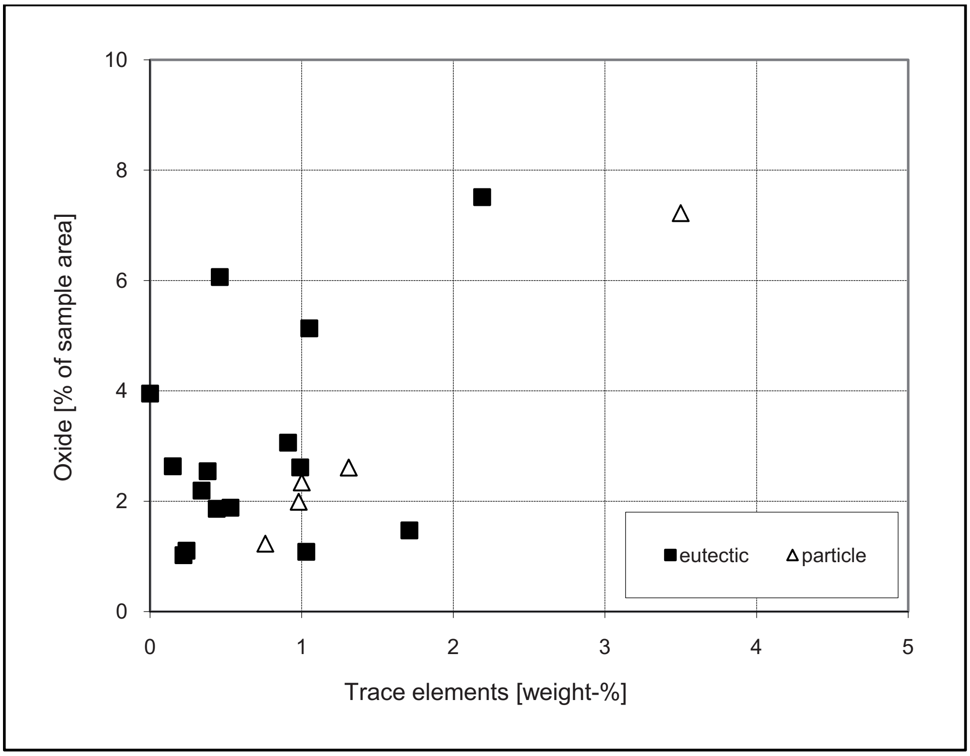


Fig. 4.17: Comparison of the frequency of different types of oxide inclusions in the Eneolithic/Copper Age horizon 1 and 2 flat axes (above); the (Cu+Cu_2O)-eutectic in a horizon 1 flat axe (below, left; sample no. 77) and oxide particles in a horizon 2 flat axe (below, right; sample no. 89).

result of the same differences in handling noted above that caused a general decline of oxides in horizon 2 flat axes.

Experimental work is required to be more precise about details of the practices mentioned and their modifications in time. But surely it is a mistake to focus on the influence of composition on casting quality to a neglect of the influence differences in procedure had on the success of the casting process. Now, this attempt at deconstructing compositional 'determinism' can be taken further by a comparison of the flat axe data to horizon 1 shaft-hole axes. The hammer axes examined for this study have an average oxide content of 1.84 % of sample area which is closely matched by the axe-adzes with an average of 1.7 %. Both values are distinctly lower than that of contemporaneous horizon 1 flat axes at 2.97 %. Like the flat axes, among the shaft-hole implements no apparent relation between trace element content and the frequency of oxide inclusions was found (see figs. 3.11 and 3.16). There is also considerable variation in both groups of shaft-hole implements. For example, among the hammer axes oxide contents range from a minimum of 0.27 % up to an outlier at 7.56 % oxides of sample area, and in some axe-adzes there are differences in oxide content between the axe arm and the adze arm (see chapters 3.2 and 3.3 for detailed discussion). This points towards the influence various aspects of handling had on this feature, such as the position of the feeder or the temperature of the molten copper. Still, there is patterning and meaningful differences between horizon 1 shaft-hole implements and flat axes that were noted above. In both the hammer axe and the axe-adze data set there are two broad groups not found in the flat axe sample with oxide contents below and above roughly 2 % respectively (compare figs. 3.11, 3.16 and 4.18). Their presence points to varying 'success' or care given in the production of shaft-hole implements as well (see above), and there is significant overlap with the oxide contents



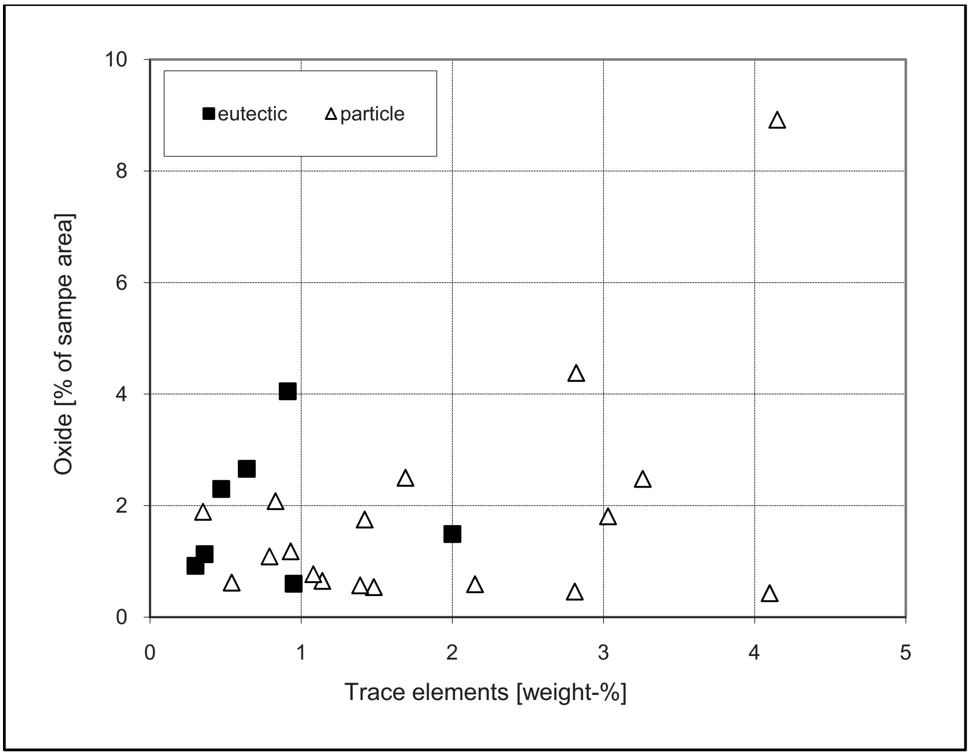


Fig. 4.18: Frequency and type of oxide inclusions in the Eneolithic/Copper Age horizon 1 (above) and horizon 2 (below) flat axes, depending on composition.

found in horizon 1 flat axes too. Yet, it is quite obvious that distinctly low oxide contents occur less frequently in the flat axe group, and the average values given above clearly indicate that shaft-hole axes in general tend to contain distinctly less oxide inclusions than contemporaneous flat axes.

Horizon 1 flat axes of Szakálhát type, for example, are known from graves of the Bodrogkeresztúr culture, that also contain shaft-hole axes, and in the hoard of Szeged-Szillér a Szakálhát type axe was associated with such shaft-hole implements as well (see chapters 3.1 and 4.1.1). Hence in a Middle Eneolithic/Copper Age context, our metallurgical

horizon 1, different groups of implements occur alongside each other varying systematically in oxide content. Oxygen absorption during casting was different, and since there is no correlation with trace element content handling was the decisive factor. Obviously, in casting flat axes there was lower control over and/or attention paid to oxygen pick-up than in the production of hammer axes and axe-adzes, where a method was employed to reduce gas absorption. It is possible that it was deliberately attempted to control oxygen pick-up and that strategies were developed to manipulate the casting atmosphere. However, we probably see the cumulative effect of minor modifications to various aspects of the casting process, with attention paid to details of handling otherwise thought unimportant, and greater care being taken when casting the more complex forms of shaft-hole implements. There are also some lower 'quality' castings in this group, which indicates that it was possible to cast such implements to lower standards. Therefore, rather than being a mere necessity to achieve such forms, with greater attention paid to shaft-hole axe production on a consistent basis compared to the flat axes, we seem to witness a reflection of wider social and ideological concerns in the field of metallurgy.

In the above discussion it was cautioned against translating this finding into a tale of high quality workshops monopolising the production of shaft-hole implements as opposed to the mundane activity of casting flat axes for day-to-day use. Rather it would appear that both groups of objects were produced by essentially the same segment of Eneolithic/Copper Age society (see discussion in chapters 5.1 and 5.4). But the differences observed are remarkable and may indicate the ability of metalworkers to 'switch' between different levels of attention or skill according to the emphasis placed on the object being cast.

4.6 Casting, Working and the Perception of the Axes

While the production of heavy shaft-hole implements characteristic of the Early to Middle Eneolithic/Copper Age declined, flat axes remained in use throughout the Late Eneolithic/Copper Age. In our horizon 2 we see modifications of the casting technique that led to a reduced oxide content. With regard to the preceding discussion it is tempting to see this process as a move in metallurgical emphasis from the earlier shaft-hole implements of horizon 1 to what weapons or tools of copper remained – an increasing interest in and closer attention paid to the casting process of various types of flat axes in horizon 2. The development is more complex, however, as the type of oxide inclusions changed at the same time that the oxygen content declined. As a result of both changes in casting technique and increasing arsenic contents, the additional hardness previously provided by the (Cu+Cu_2O)-eutectic was lost. Instead metalworkers took to cold working flat axes of horizon 2 (fig. 4.19). This modification of the *chaîne opératoire* allowed the smith to only stabilise or slightly increase hardness values (see below). But it added complexity to the production process and in this respect can be taken to support the assumption that greater emphasis was placed on horizon 2 flat axes.

Hardness readings obtained on horizon 1 hammer axes range from 59.8 HV to 117.1 HV in sample nos. 45 and 153, and the average of this group is at 82.31 HV. Horizon 1 axe-adzes have a slightly higher average hardness of 94.29 HV, and individual values range from 66.8 HV to 129.1 HV (sample nos. 105-1 and 107-2). Contemporaneous horizon 1 flat axes have hardness readings between 60 HV and 140.7 HV in sample nos. 46 and 55. Their average hardness is at 94.7 HV (fig. 4.20). Hardness in all three groups of horizon 1 implements was dependent on the presence of the (Cu+Cu_2O)-eutectic, i. e. casting technique, but it was also influenced by deformation induced upon surface finish and/or initial use. With this in mind the slight differences observed in average value, minimum and maximum hardness should not be over-interpreted. The mechanism involved is the same, i. e. oxide hardness adding to the strength and durability of these implements, but as a rule no deliberate attempt was made to manipulate and increase hardness by final cold work (see chapters 3.2, 3.3 and 4.2).

Most flat axes of horizon 2, on the other hand, were subject to a more or less strong cold hammering (see chapter 4.3). This modification to horizon 2 *chaîne opératoire* and the mechanism exploited to improve mechanical properties should not, however, in a straightforward sense be seen as 'progress'. Rather, it implies complex change in the perception of the axes themselves and of their production context. The oxide data was taken above to imply a move in metallurgical concern from horizon 1 shaft-hole implements to horizon 2 flat axes. Casting also remained of importance since poor casting quality could have meant high porosity and early failure of an axe upon use. However, forging now gained additional importance as in the unworked state mechanical properties were poor. This is easily illustrated by a minimum hardness of 50.5 HV (sample no. 154) in this group of horizon 2 flat axes that corresponds to undeformed pure copper (fig. 4.20). Since after surface finish (polishing) all traces of previous hammering most likely were erased, this also carries implications for the subsequent life cycle of these axes. If they were exchanged, securing knowledge of their provenance and reliance upon attentive working would have become of greater importance than in horizon 1.

The maximum hardness in the group of horizon 2 flat axes is at 163.3 HV in sample no. 136 clearly benefiting from the rather high trace element content of this piece and very strong cold work otherwise rarely found in this group. There are just two axes at all, however, at hardness values above 150 HV, and the majority of them fall in the 100 HV to 140 HV range (see fig. 4.12). The average hardness is at 110.4 HV. Compared to horizon 1 with most flat axes falling in the 60 HV to around 110 HV hardness range (see fig. 4.8; average: 94.7 HV), this may represent 'progress' of some kind. But there is significant overlap, and un-attentively worked horizon 2 axes that entered circulation had poorer properties than most horizon 1 ones (see above). More experimental work is required to determine what an increase

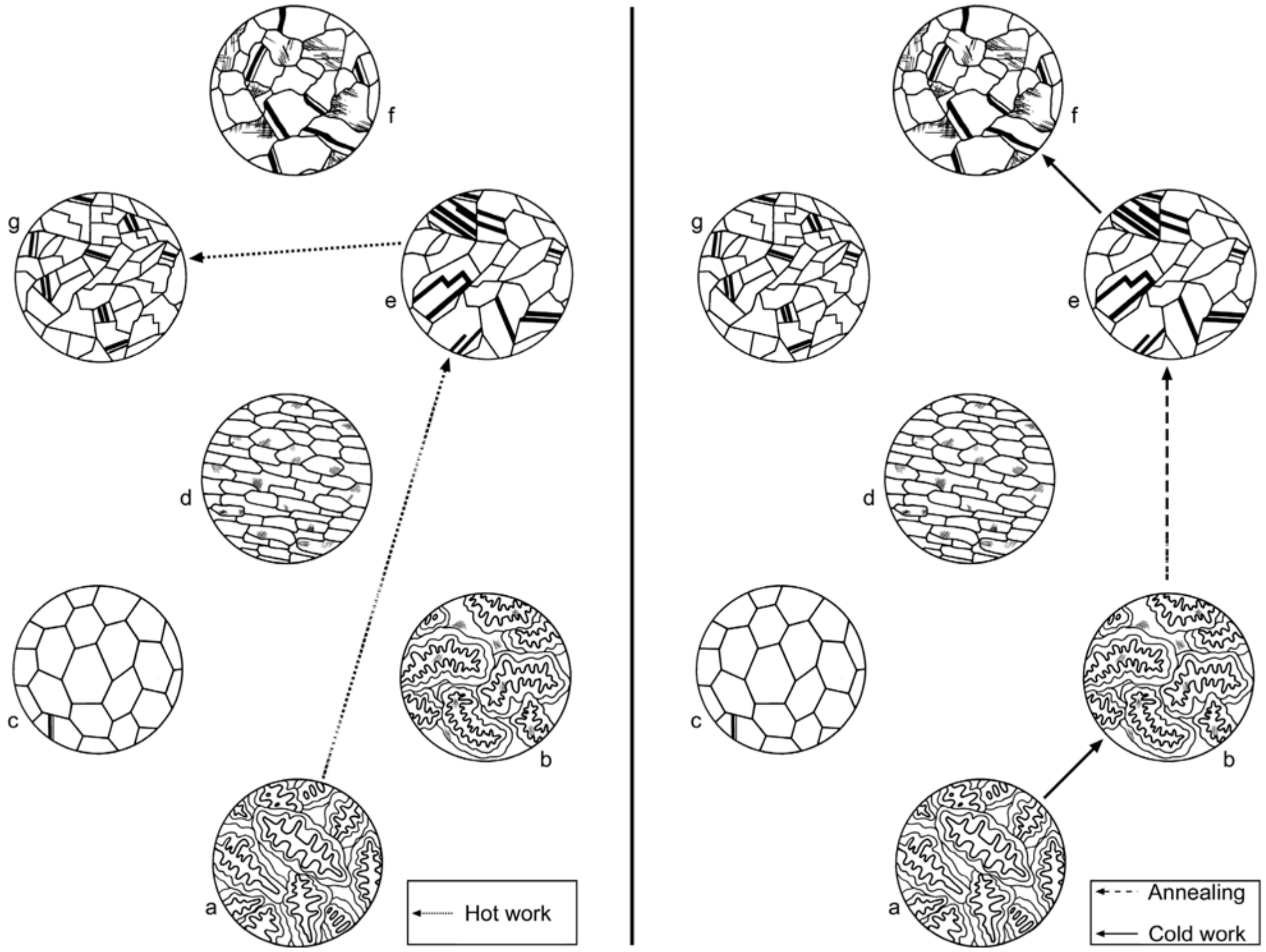


Fig. 4.19: Comparison of the chaîne opératoire for Eneolithic/Copper Age horizon 1 axes (left) and horizon 2 axes (right).

in hardness from say 90 HV to 110/20 HV exactly implies in terms of durability and life-span of such implements. But it would appear that irrespective of such minor variation for most applications the initial rise from an as-cast hardness of about 50 HV to a broad hardness range about 100 HV was most important. Irrespective of whether their hardness was at 90 HV or 110 HV, in any case both horizon 1 and horizon 2 axes would have required frequent re-sharpening.

It is unlikely, therefore, that the somewhat higher average hardness of horizon 2 flat axes significantly influenced their performance. The switch to cold work primarily compensated for a loss in earlier oxide hardness. The move in metallurgical 'emphasis' to horizon 2 flat axes postulated above is not directly related to mechanical properties alone. Rather it arose from an overall increase in the complexity of their production process (fig. 4.19) as well as of their perception during use and in exchange. Casting in any case is critical for a copper implement's appearance, performance and durability. But there is tolerance in what casting quality in terms of porosity, gas absorption and oxide inclusions is acceptable in a given context depending, for example, on requirements for practical activities and/or display. With this in mind it was argued above, that the decline in horizon 2 flat axes' oxide content is not merely a technical feature, but reflects an express concern on behalf of metalworkers, that previously was directed towards horizon 1 shaft-hole implements rather than towards flat axes. Additional complexity was added in consequence of the parallel move to cold work. During horizon 1 forging was intense but conceived solely as a shaping operation. Now it determined mechanical properties, use and perception of the axes.

In the previous sections different aspects of oxygen pick-up, mechanical properties, trace element contents and procedure were discussed. It is apparent that with regard to all of these we must beware of modernist conceptions in our judgement on Eneolithic/Copper Age metalworking. Cognitive aspects of early metallurgy – knowledge gained by prehistoric metalworkers of the raw materials they were working, choice beyond mere functional improvement and subtle changes through time to traditional practice – must not be neglected in favour of an approach focusing on composition and straightforward 'progress'.

From a modern perspective a high amount of copper oxide and the presence of the ($Cu+Cu_2O$)-eutectic in particular is the result of a 'deficiency' in casting thought to embrittle the material. But in our Copper Age horizon 1 sample the eutectic provided an alternative mechanism to improve performance, and 'primitive' casting technique turned to the good. Much the same is true for casting properties

Hardness (Pt. 1, HV0.1)	*CA horizon 1: Hammer axes*	*CA horizon 1: Axe-adzes*	*CA horizon 1: Flat axes*	*CA horizon 2: Flat axes*
Minimum	59.8	66.8	60	50.5
Maximum	117.1	129.1	140.7	163.3
Average	82.31	94.29	94.7	110.4

Fig. 4.20: Average hardness, minimum and maximum hardness readings obtained on the Eneolithic/Copper Age shaft-hole axes and flat axes examined.

and composition. The older axes mostly consist of rather pure copper while the younger horizon 2 ones saw the introduction of arsenical copper – at least some of them. This change in composition would typically be thought to have had a beneficial effect on casting quality. Instead is can be shown that both an overall decline in oxide frequency and the replacement of the eutectic oxide type in the younger axes does not directly correlate with trace element content. It is indicative of a number of minor modifications to various aspects of the casting process and overall attentiveness, which shifted in the course of time from shaft-hole axes to flat axes.

Similarly, with regard to forging one would expect that the differential work hardening properties of pure and arsenical copper were recognised and taken advantage of, but this was not the case for the horizon 2 axes examined. The preferential choice of arsenical copper for contemporaneous daggers points to an alternative interest in colour (see chapter 2.4). However, forging of horizon 2 axes was not ‘primitive’ either, but implies that metalworkers were actively interested in the hardness of their axes. In addition, good knowledge of the raw material used can be assumed (see chapter 4.3). The dagger evidence suggests that copper with higher arsenic contents was recognised, for instance in terms of its different colour, but it is apparent here why its potential for greater hardness was not realised. At least for a range of arsenic contents up to 2 % to 3 % there is an initial closeness and parallelism in cold working behaviour and hardness obtained (see fig. 4.15). In no way is it an obvious conclusion from this behaviour that with continued deformation for higher arsenic contents further increase in hardness would be stronger. The absence of any corresponding experimentation reflects an already established horizon 2 tradition of working the more common relatively pure copper, which prevented recognition of the greater potential offered by higher arsenic contents (Kienlin/Bischoff/Opielka 2006; Kienlin 2008a, 106–111). There is a clustering around the point at which further increase in hardness is delayed, but given that relatively pure copper with trace element contents up to about 1 % was the norm and higher arsenic contents were rare, the procedure that resulted was insensitive to composition. This approach to working might be termed ‘pragmatic’ but certainly not ‘primitive’. Following this fairly standardised method of working even pieces with trace element contents below 1 % reached hardness values above 100 HV on a regular basis.

In a way this foreshadows the Early Bronze Age situation when, at least during BA A1, different traditions of working fahlore copper and tin bronze coexisted. These groups, too, are distinguished by their composition and forging technique, yet within each of them there is no systematic variation in strength of cold work with varying trace element and tin contents. For example, Neyruz type axes consisting of copper are cold worked rather weakly while the tin-alloyed examples of this type show a tendency for more intense cold working. The opposite development is apparent for the Saxon type axes. There are different implementations of the knowledge of tin bronze, but the actual tin contents did not result in a further differentiation of cold working. It was of primary importance to increase significantly the hardness compared to the starting point of an as-cast or recrystallised microstructure. Similar to the Copper Age situation this was done by a more or less standardised cold working, specific to each compositional group but irrespective of the individual axe’s composition (see chapter 7).

To conclude this section, another comment on an earlier version of this study has to be acknowledged: P. Bray (Oxford) raised the question whether the replacement of older *Reinkupfer*, broadly our Eneolithic/Copper Age horizon 1, by arsenical copper, broadly our horizon 2, may have been due to technological change in casting and working rather than just to the exploitation of different types of copper ores and ore deposits (Bray pers. comm. 28. 6. 2010). From this perspective the older horizon 1 approach to forging observed in this study, the long heating times in what has been called hot work may have removed trace elements such as arsenic through oxidative loss. In horizon 2, after the end of hot working, this effect would have ceased and in addition changes in casting technique might have allowed the object to retain more trace elements than previously was the case.

Since this is not a study on the provenance of copper and the development of smelting technique, throughout this work there is certainly a tendency to refer changing compositional patterns back to the mines and smelting process without due detailed discussion. Instead, this work has focussed on whether the properties of the different types of copper and copper alloys were realised and how they relate to the development of methods of casting and forging (see also the discussion on the Bronze Age evidence below and the uses made of different grades of fahlore copper). Bray, on the other hand, asks if composition is an independent

variable at all and to what extent the approaches to casting and working discussed had an influence on composition itself. I very much agree with this approach and certainly the influence that the re-use of copper had on composition is another problem that is generally neglected. In a way this is an old debate that goes back to discussions in the wake of the 1960s SAM-project (Junghans/Sangmeister/Schröder 1968). Typically, it was the (international/British) critics of SAM that stressed the influence of smelting and subsequent working on composition, while the continental (German) approach to provenancing still has it that composition is largely a reflection of the copper ore deposits exploited (for a summary of the original debate see Härke 1978). The latter is certainly not the approach advocated in this study and attention has been repeatedly drawn to problems with the notion of a clear-cut sequence from the upper, oxidised regions of ore deposits to the deeper, sulphidic ore bodies derived from a simplified notion of ore bodies and technological progress. This is also reflected in the composition of the axes examined in this study because neither do all horizon 1 axes consist of pure copper nor do all younger ones from horizon 2 contain trace elements such as arsenic in significant concentrations. In the Bronze Age section that follows, in particular, a decentralised approach to mining is argued for that may have caused such compositional variation and had an influence on the acceptance of various types of sulphidic (fahlore) copper by metalworkers of that period.

Still, it is important to comment on some of Bray's suggestions and see if the assumption stands in principle that composition may be used as a kind of background to the discussion of technological change, or if it is the other way round that the approaches to casting and forging described caused compositional patterning in the first instance. As far as working is concerned it is possible that continued heating (horizon 1 hot work) causes oxidative loss of arsenic etc. on the surface of an artefact. But low trace element contents in copper objects from this horizon are not only known from metallographic samples; in fact this so-called *Reinkupfer* was first defined by drilling samples which extended to the core of the objects examined. So it is unlikely that low trace element contents in our horizon 1 are a result of the specific forging technique employed. Similarly, the somewhat higher arsenic contents in a number of horizon 2 implements are not a consequence of the changes in forging technique noted. It is possible that somewhat more arsenic etc. was retained along the outer surface during the short cycles of annealing only. But this does not account for differences in bulk composition shown by drilling samples. Casting is another matter and more difficult to comment on. It has been argued above that the differences observed in oxide contents of horizon 1 shaft-hole implements and flat axes are a reflection of greater 'emphasis' put on the production of the former. Obviously, this is an explanation very much framed in terms of culture. It is frankly admitted that experimental work is required to be more precise on the nature of the 'cumulative effect of minor modifications to various aspects of the casting process' referred to above. A more down-to-earth explanation may refer, for example, to the likelihood that for the shaft-hole implements copper had to be melted separately before being brought together from many crucibles for one big cast (Bray pers. comm. 28. 6. 2010). Such differences in approach or rather in scale may in fact explain the different frequency of oxide inclusions in both groups. But they did not affect the type of oxide present in horizon 1 shaft-hole axes and flat axes (typically the $Cu+Cu_2O$-eutectic) nor did they apparently affect the composition which is broadly the same in both groups as well.

After the decline of heavy shaft-hole implements in horizon 2, it has been suggested, attention shifted to the production of flat axes. Both the general decline of oxides in horizon 2 flat axes and the predominance of a new type of oxide inclusions were explained by differences in handling of the casting process. For reasons discussed above, it is thought likely that in both horizon 1 and 2 casting took place in close moulds. Thus, it is unlikely that the differences observed are an open versus closed mould pattern. The approach to casting flat axes was broadly similar in both horizons, and there is certainly not the *one* innovation in casting technique that might account for the changes in oxide inclusions found in horizon 2 flat axes. Nor is there any obvious reason why composition should have been affected by casting technique and larger amounts of arsenic be retained. Both horizons are not separated by clear-cut compositional patterns anyway. Despite what has been said above, it is most likely that in this case at least, the compositional patterning observed, i. e. somewhat higher arsenic contents in some of the younger horizon 2 objects, broadly refers to gradual changes in copper sources and corresponding exchange systems. From a perspective of casting and working it has been shown that such compositional variation was not a major determining factor for the changes observed. Admittedly, it is unsettling to take refuge to such commonplace phrases as 'general care given' to describe this development. But it is likely that it is precisely the cumulative effect of minor variation only to traditional practice over a certain period of time that has been discussed at some length on the preceding pages.

5
The Axes in Context I: Copper and 'Copper Age' Society

5.1 The Function and Meaning of the Axes

In terms of their function the shaft-hole axes and the flat axes of horizons 1 and 2 have received quite different interpretations. They are considered everything from multi-purpose implements or specialised tools for use in agriculture, wood-working or mining to weapons or prestigious status symbols without practical applications but suitable for ritual deposition, burial and/or exchange in competition for social preeminence or political leadership (see e. g. Novotná 1970, 26; Mayer 1977, 14–15; Patay 1984, 18–20; Žeravica 1993, 15–16; cf. Boroffka 2009a, 251). These are not mutually exclusive categories, and of course most of the suggested uses are possible. The latter interpretation, in particular, carries heavy implications for Copper Age society, which we have to return to below. Before, however, it may be useful to summarise some of the above findings, and discuss their implications for the function and the meaning of the axes focusing on a) their material properties and aspects of production, and b) on the contexts, from which these objects are known.

Typically, it is only in the older literature that one finds reference to superior properties upon use of the earliest copper weapons and tools (e. g. in some of the above quoted PBF-volumes). Instead, in the meantime it is mainstream to argue that for an extended period of time implements of stone or flint, bone and wood performed equally well as copper ones or better (e. g. Ottaway/Roberts 2008, 212–215), and "people did not *need* copper tools; they *wanted* copper tools" mainly for aesthetic or socio-cultural reasons (Roberts/Thornton/Pigott 2009, 1012 paraphrasing C. S. Smith). Now, it is certainly true that pure undeformed copper with a low as-cast hardness of around 50 HV was of limited use for the production of proper tools. In fact, it is doubtful if the Eneolithic/Copper Age axes examined were the implements of choice for many practical activities such as working wood or cutting down trees. Still, we have seen that by various mechanisms, which changed through time, hardness was raised (see chapters 3.2, 3.3, 4.2 and 4.3). It is certainly not true that hardly any of the axes of our Eneolithic/Copper Age horizon 1 was used, and that they were intended for display and deposition only, as suggested by D. Bailey (2000, 213–214).

By the presence of ($Cu+Cu_2O$)-eutectic inclusions the average hardness of horizon 1 shaft-hole implements was raised to 82.3 HV (hammer axes) and 94.3 HV (axe-adzes) with maximum values at 117.1 HV and 129.1 HV respectively (fig. 5.1). Similarly, contemporaneous flat axes have an average hardess of 94.7 HV that is well above pure undeformed copper, and occasionally hardness values up to about 140 HV are reached. Experimental work suggests that even such a limited increase in hardness may have a substantial effect on the use-life of such copper implements, provided they were frequently re-sharpened (Kienlin/Ottaway 1998). In a number of both the shaft-hole axes and flat axes from horizon 1 deformation at the cutting edge and along the outer surface of the samples gives direct evidence of such use (figs. 3.10 M17, 3.15 M17 and 4.6 M17). It has been shown that even this rather weak initial deformation induced additional hardness, which proved beneficial for subsequent activities. Despite this mechanism that further improved performance, the axes' potential for practical use was certainly limited. But it must not be neglected either, and the relatively small number of pieces with massive signs of use-wear must not be mistaken for the total absence of practical use (Bailey 2000, 214). Rather, it is suggested that frequent re-sharpening was the rule, i. e. an adequate use made of these implements, and most axes that suffered extensive damage were certainly re-cast. The surviving ones only show the initial stages of use. The attempt to infer the axes' function from those that came upon us mainly from hoards and graves alone is to ignore an important part of Eneolithic/Copper Age life and reality.

Ötzi, the Iceman, and his axe, dated to c. 3300–3200 cal BC, are contemporaneous with or somewhat younger than our horizon 2 (see below) rather than with the horizon 1 shaft-hole implements and flat axes under discussion right now. But surely M. Pearce (2009) is right to argue in a recent paper, that Ötzi's axe apparently was part of an utilitarian tool kit, and such implements were more common and in daily use than we tend to imagine. Ötzi's axe was barely visible in its hafting and was hardly carried along for its 'flash' or 'bling' (Pearce 2009). By extension one may argue that our horizon 1 flat axes as well "were normally [...] practical tools, whose function was more utilitarian than for display." (Pearce 2009, 282). With some restrictions (see below) this may also apply to many of the horizon 1

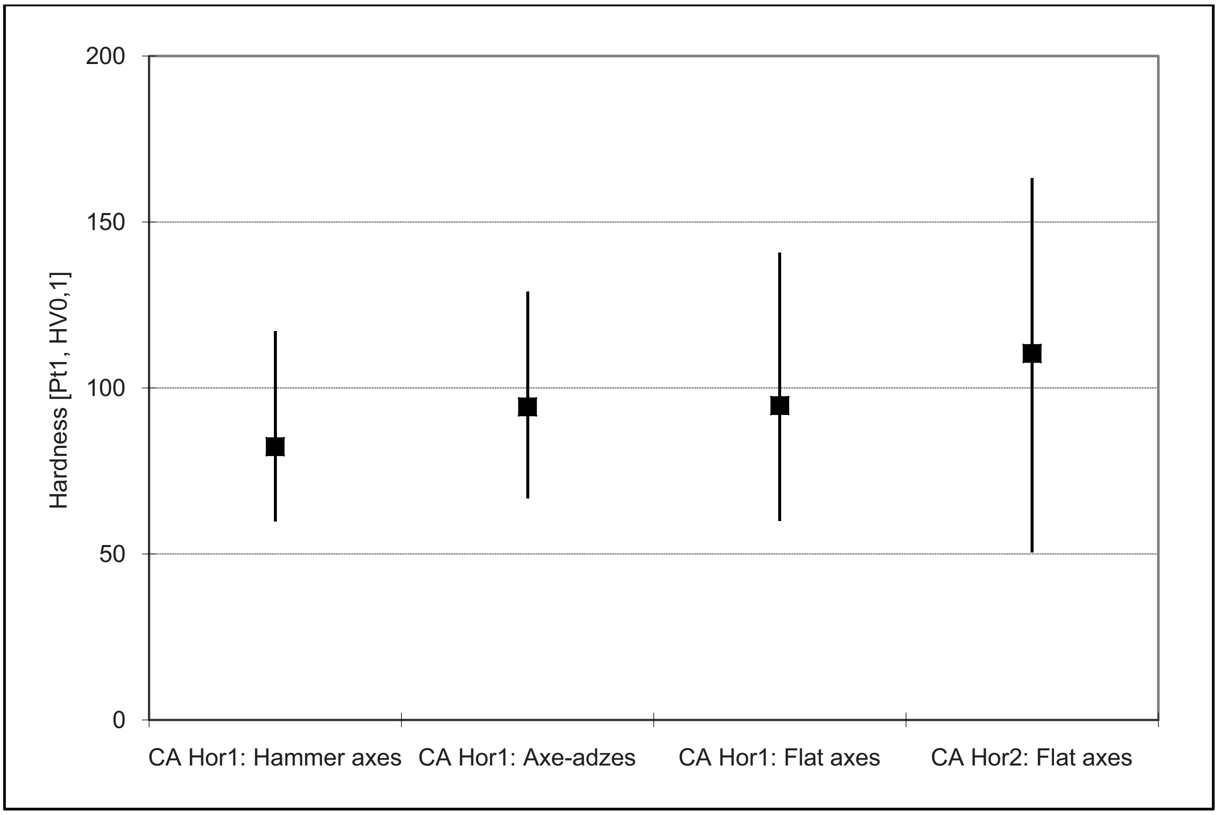


Fig. 5.1: Graphic presentation of the average hardness, the minimum and maximum hardness values for the Eneolithic/Copper Age shaft-hole axes and flat axes examined.

shaft-hole implements; at least to those axes with a proven record of use. Use in this sense may include occasional conflict, and they were certainly restricted to just some practical activities, that need not correspond to our modern use of steel axes. Furthermore, we may expect that the physical use was of limited intensity. But in consequence it is likely that such implements were present in people's daily life on a more regular basis than our interest in their use in formalised social display, ceremonies and burial ritual implies. Rather than focusing on their conspicuous deposition during burial ceremonies (Bailey 2000, 213–214), it is likely that it was precisely their presence in more mundane situations and activities (Miller 1985, 191–193), that substantiated the axes' suitability as markers of (male) habitus and/or as an expression of a person's given role or position (Kienlin 2005b, 7–11; Pearce 2009, 282).

Having said that, it is obvious that by their sheer size and weight at least some horizon 1 shaft-hole axes were beyond use (Novotná 1970; Vulpe 1975; Todorova 1981; Patay 1984; Žeravica 1993). There certainly was no general 'over-use' of copper, but some pieces clearly required an amount of copper in their production that was – in D. Bailey's (2000, 213) terms – "outrageously disproportionate to the use of copper to make other things." It is here that we enter the domain of what he called "expressive material culture" that is thought to distinguish the Eneolithic/Copper Age from the preceding Neolithic (Bailey 2000, 209–239). As noted above, from a perspective of production and material properties this should not be taken to imply that the axes were never used and use was never intended. But their production parameters, namely the hot working for shape, the lack of final cold work and the careful polishing, show that their production was determined by an overriding interest in shape, good surface properties and outward appearance as well as maybe size and weight. No deliberate attempt was made to improve their mechanical properties upon final working and benefit from work hardening. What additional hardness there was – i. e. in excess of pure undeformed copper – that enabled their use in practical activities was mainly provided by the ($Cu+Cu_2O$)-eutectic and may be seen as a side-effect of 'shortcomings' in casting technique (see chapter 3.5). The hardness thus achieved was incidental, and obviously it was felt to meet demands in daily use including practical activities as well as conflict and display without further ado. As far as their production is concerned the same is true for contemporaneous flat axes (see chapter 4.2). But unlike those the shaft-hole axes after hafting would still have displayed command over an implement of visibly 'a lot of copper', and proper care may have been given to preserve their characteristic 'flash' or 'shine' by frequent polishing.

It is likely that copper – alongside other 'exotic' materials such as gold, shell, pigments like malachite or ochre and graphite decorated pottery, some of which first came into use during the period in question such as gold – was appreciated for its expressive qualities (Bailey 2000, 209–239). Still, the axes show that this interest in visually exciting materials should not be reduced to their decorative

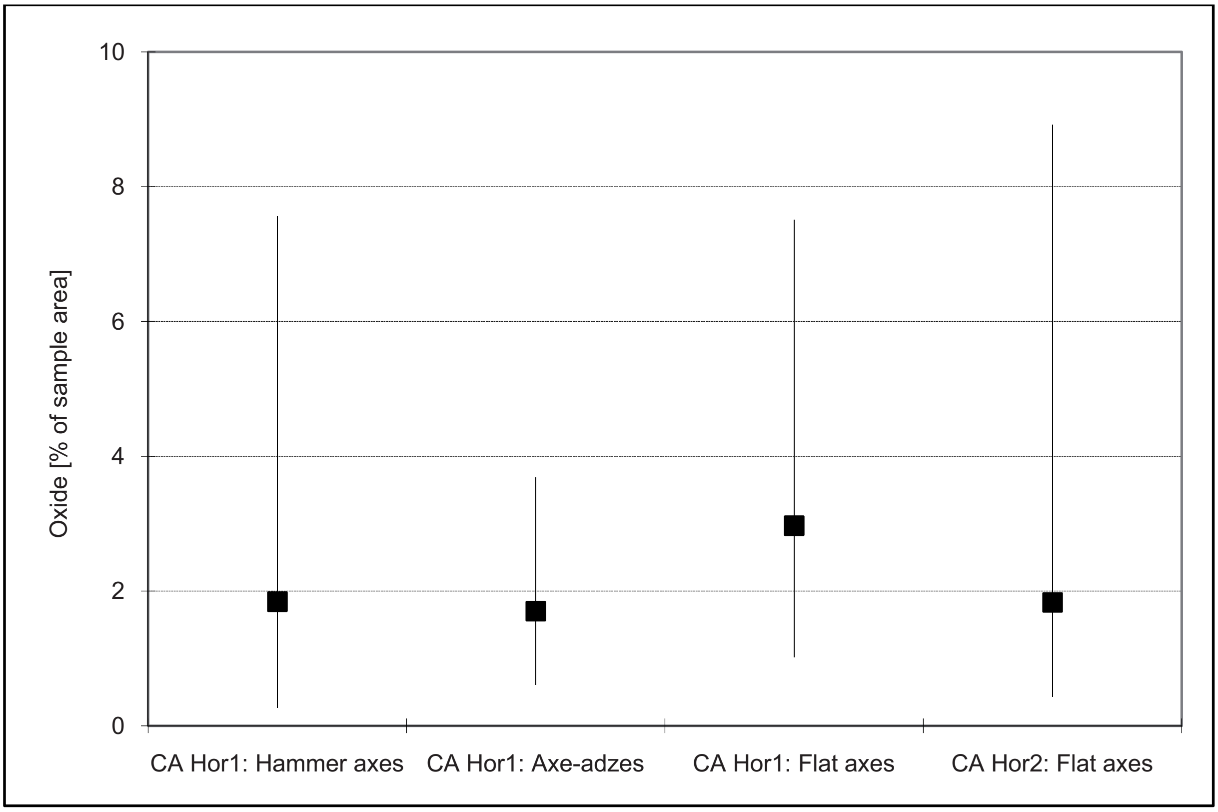


Fig. 5.2: The average oxide content with the corresponding minimum and maximum values in oxide content for the Eneolithic/ Copper Age shaft-hole axes and flat axes examined.

potential or the 'extravagant inutility' of the new artefact types and shapes produced thereof (contra Bailey 2000, 218, 235–236). In this period there are both shaft-hole implements, which could be used but certainly carried greater potential for social and/or ritual connotations, *and* flat axes of copper, that in their haft would have lost much of their flashing appeal and may simply have continued the tradition of comparable stone implements.

It is likely that such differences in use and symbolic 'potential' are also reflected in the domain of production. In chapter 4.5 it was noted that with average oxide contents of 1.84 % and 1.7 % for hammer axes and axe-adzes respectively horizon 1 shaft-hole implements tend to contain distinctly less oxide inclusions than contemporaneous flat axes with an average of 2.97 % of sample area (fig. 5.2). The same basic routines were followed and decisions taken in the production of all three groups of artefacts. But within this broad tradition there occurred minor variation during the casting process that is informative of differences in emphasis put on the production of shaft-hole axes on one hand and flat axes on the other. The resulting variation in oxide contents may relate to the technical requirements on casting the more complex shaft-hole implements. But it is tempting to interpret these differences in terms of differential care given or knowledge and skills involved in their production. It is suggested that this finding may reflect the different meaning and value attached to both groups of objects.

Now, lest this suggestion be misread as a two-tier system of the elite-controlled production of shaft-hole implements in specialist workshops and village foundries casting flat axes for day-to-day use, let us briefly turn to the role of copper in Eneolithic/Copper Age society in more general terms. There is a widespread tendency to link metallurgy to the emergence of socio-political hierarchisation. The control over the production and/or circulation and display of prestigious copper objects is seen as the medium through which individuals or social groupings competed for wealth, status and/or power. This point will be examined in greater detail below, and evidence for social hierarchies is found wanting (see chapter 5.3). Hence, the position taken with regard to copper and Copper Age society is akin to the approaches of A. Whittle (1996) and D. Bailey (2000). In Tiszapolgár and Bodrogkeresztúr graves, for example, there is little evidence of hereditary status. Authority was derived from age and personal achievement but hardly extended beyond the co-residential unit or the limits of the individual's lifespan (Lichter 2001, 289–291, 344–349). Among the copper implements found in the (male) graves of both culture groups there are occasional shaft-hole axes of some of the types examined above. But it is no use directly translating variation in the expression of (male) personal identities or habitus and possibly 'economic' success into differential access to status or power (Whittle 1996, 73–76, 94–96, 116–121; Bailey 2000, 208–218, 235–237). There are different kinds of personal identities and levels of authority, and various motivations guide human action and strategies. They are negotiated in a specific cultural

context, and they are entangled with communal or corporate identities, as well as with the 'interests' of collectivities such as the household, kin-groupings, the village or the tribe on various levels (see chapter 5.2).

We disagree with Bailey (2000) on the sole or preferential use of copper in conspicuous mortuary display. It is suggested he neglects both the context of production and the presence and visibility of copper in contemporaneous settlement and daily life (see above). But surely, he is right in pointing out that the role of copper as well as other items of expressive material culture must not be reduced to the accumulation of abstract individual 'wealth' or elite control over their circulation and deposition (Bailey 2000, 217–218, 235–236; cf. Whittle 1996, 116–121). For sure, the acquisition and working of copper, as well as other materials like gold, involved some special knowledge and skills, and the ability to establish and maintain exchange networks may have lent itself to manipulation and aggrandising behaviour. But such ambitions were firmly set in a communal context and checked by corporate ethics (Whittle 1996, 120). Possible differences in (production) knowledge or participation in exchange are not always equivalent to permanent political hierarchies. There may be potential for aggression, the accumulation of wealth and competition in every human society. But they operate at both the individual and group level, and they are rarely the sole motivations or processes at work.

Hence, with regard to the effect of copper and copper-working on Eneolithic/Copper Age society we should expect that this offered a *variety* of "new ways for expressing the human condition and, more particularly, one's relationship both to a particular place, be it household or village, and to other people", and that "a range of personal identities ... were played out through a particular set of materials such as metal or shell, in specific contexts, such as burials, and ceremonies, such as rituals of household or village membership." (Bailey 2000, 238, 235–236). Against this background, it is suggested that the differences noted in the production of shaft-hole axes and flat axes do not refer (in terms of the traditional interpretation) to any different levels of craft specialisation or elite consumption and exchange of particular objects produced. Rather it is likely that both groups of objects were made by essentially the same segment of Copper Age/Eneolithic society (see chapter 5.4). But with various levels of skill involved and attention paid, their production underscores the differences in emphasis subsequently put upon these objects during use – in the widest sense including practical activities and/or social and ritual display – and reflects wider symbolic concerns pervading society as whole.

During the later Eneolithic, our horizon 2, the earlier emphasis on the shape and visual quality of copper objects came to an end. The production of heavy shaft-hole implements declined, and more generally speaking the use of 'expressive material culture' lost its importance. Mundane forms such as new types of copper flat axes were the sole survivors, and it has been shown in chapters 4.3 and 4.6, that some of the attention paid to shaft-hole axes before was now turned to the production of 'better' flat axes instead. There is a decline in the average oxide content of horizon 2 flat axes (fig. 5.2), that is indicative of this increase in overall attentiveness and is due to modifications to various aspects of the casting process (1.83 % of sample area compared to 2.97 % for horizon 1 flat axes). It has been argued that this development not merely reflects the beginning use of arsenical copper, but an express concern of metalworkers upon casting, that previously was directed towards horizon 1 shaft-hole implements rather than towards flat axes. Things are not all that easy, however, and horizon 2 flat axes did not simply replace earlier shaft-hole implements in metalworking and people's symbolic 'concerns', for at the same time there is a shift from hot working to cold working (fig. 5.3). Besides the improvement in casting technique mentioned, additional complexity can be observed in a cyclical working and the succession from cold work in the as-cast state via annealing to final cold hammering. However, this modification to the *chaîne opératoire* and corresponding effort was directed towards different ends than during the previous period. During horizon 1 forging was intense but conceived as a shaping operation only. Now it determined the mechanical properties and use of the axes – an approach that went fundamentally unchanged throughout the Bronze Age.

In absolute terms there is only a slight increase in the average hardness of horizon 2 flat axes (fig. 5.1), and the switch to cold working primarily compensated for a loss in earlier horizon 1 oxide hardness. In terms of their durability the potential of horizon 2 flat axes for practical use as well was still limited. However, there is evidence of use wear (see fig. 4.10 M17), and like their horizon 1 forerunners they were clearly put to some kind of practical activities. Unlike horizon 1, however, this is reflected already in their production. There is clear evidence, that metalworkers were interested in the hardness of the axes, and some broadly defined cold work of medium strength was carried out in order to increase their durability. However, the move in metallurgical 'emphasis' to horizon 2 flat axes – both in casting and working – is not directly related to mechanical properties alone. Rather it arose from an overall increase in the complexity of their production process as well as from their perception during use and maybe in exchange.

Like their forerunners, flat axes of horizon 2 were barely visible in their hafting, and they did not provide an equivalent to the symbolic and expressive potential of earlier shaft-hole implements. It has been mentioned that during horizon 2 copper rich in arsenic was preferentially used for daggers, which thereby attained a conspicuous silvery colour. Albeit in a different form, it is likely that this finding indicates a continuation of the earlier interest in the expressive qualities of copper objects. Flat axes of horizon 2, however, obviously take up the rather 'practical' connotations already apparent in their horizon 1 forerunners. Reference to Ötzi and his axe has already been made (Pearce 2009), and the broadly contemporaneous or somewhat older Altheim type axes etc. as well were

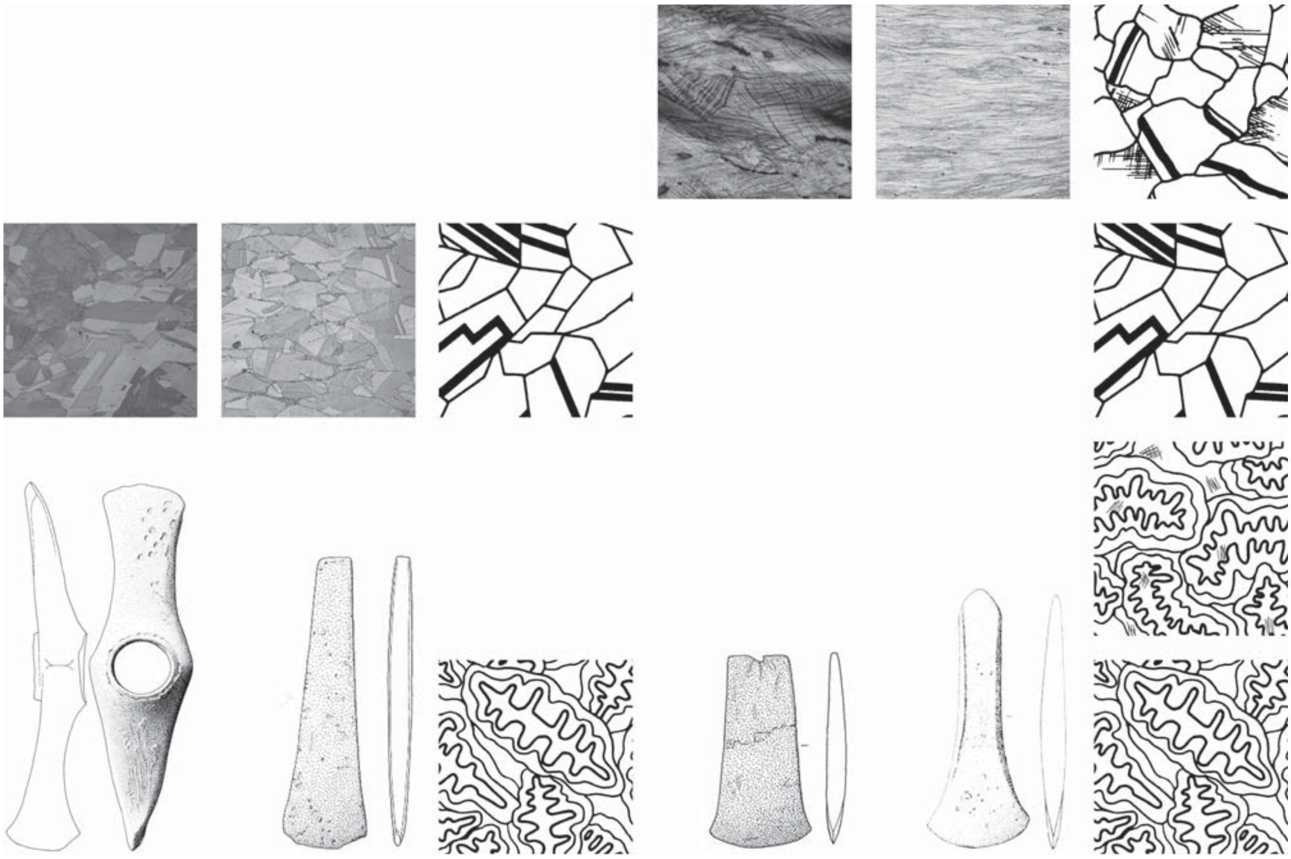


Fig. 5.3: Comparison of the suggested chaînes opératoires for the finishing of Eneolithic/Copper Age horizon 1 axes on the one hand (shaft-hole axes and flat axes) and Eneolithic/Copper Age horizon 2 flat axes as well as Early Bronze Age flanged axes on the other.

certainly in more common use than we tend to expect. Use, that is to say, with all the restrictions on prolonged practical activities mentioned earlier and the need of frequent re-sharpening. Use, on the other hand, that was much more clearly anticipated and expressed through a concern with good mechanical properties during production than previously was the case in horizon 1. Its not only its 'flash' or 'bling' that qualifies material culture such as the axes for the expression of personal identities but also routine association with its bearer and regular handling. Hence, in comparison with horizon 1 shaft-hole implements the younger flat axes certainly point towards a significant shift in symbolism and possibly to an impoverishment as well. But there is also an element of continuity in the expression of categories of persons and (male) habitus via implements such as horizon 1 and 2 flat axes.

5.2 Approaches to Eneolithic/Copper Age Society

The south-eastern European Eneolithic or Copper Age is noticeable for its large number of often fairly massive copper artefacts. It was their presence that initially gave rise to the definition of a Copper Age period to be added to the previously tripartite system of European prehistory – Ch. J. Thomsen's Stone, Bronze and Iron Ages (Lichardus 1991b). Artefacts such as the elaborate shaft-hole axes prompted discussions on an independent origin of metallurgy in south-eastern Europe (e. g. Renfrew 1969; Pernicka 1990, 32–40), and the question of multiple centres of metallurgical innovation versus single invention in Eurasia is still subject to debate today (e. g. Roberts/Thornton/Pigott 2009). Similarly, there is still no consensus on what the 'Copper Age' actually is. Even in the Carpathian Basin and on the Balkans traditional definitions heavily rely on the appearance of copper artefacts (see Lichardus 1991b), i. e. technological aspects, and attempts at a definition drawing on changes in economy, society and ideology (e. g. Lichardus 1991c) are controversial. In central and north-western Europe, for example, massive copper objects are missing during the 5th and 4rd millennia BC except for occasional import finds. Neolithic traditions seem to persist, and suggestions to draw a line from the Near East, via south-eastern Europe to the Atlantic fringes (e. g. Müller-Karpe 1974; Lichardus 1991c, 770–788; Klassen 2000, 17–27, 295–301; 2004, 325–337) are challenged by those advocating a more differentiated approach to local society and economy, and denying widespread change or assimilation that supposedly affected 'Copper Age'/Late Neolithic groups (e. g. Lüning 1996; 2000). This is not the place to provide a comprehensive review of debates on Copper Age social structure. Yet it is worthwhile to have a look at some of the models discussed since they may provide a starting point for the attempt to outline the social context of early metallurgy during the Eneolithic/Copper Age.

Fig. 5.4: Plan of the tell site Poljanitsa (phases IV and VIII) in Bulgaria (after Parzinger 1993, tab. 192.8/9; Todorova 1982, 212 fig. 165, 220 fig. 173).

As far as central and south-eastern European archaeology is concerned a classic definition of the Copper Age was given by J. Lichardus (1991c, 786–788). To him the Copper Age is a "complex structure of economy, society and religion" comprising amongst other features the emergence of complex society, social hierarchisation and craft specialisation, central places and fortified settlement as well as the use of prestige goods to express individual status. Cattle breeding is thought to have been of increasing importance, the knowledge of plough and wheel – elements of A. Sherratt's (1981; 1983) 'Secondary Products Revolution' – led to an economic intensification and the mining for copper required specialist knowledge and organisational effort. All of this caused changes in ideology with ritual, belief systems and burial customs reflecting an increasingly complex and differentiated society. In accordance with the work of other authors (e. g. Pleslová-Štiková 1977; Neustupný 1981) Lichardus' definition is polythetic, therefore not *a priori* privileging any individual innovation. Yet there is an emphasis on the role of metallurgy as a cause of the assumed societal change (Lichardus 1991c, 787–788). It is quite clear that not all of the elements listed appear at the same time throughout 'Copper Age' Europe (e. g. the use of secondary products such as traction, milk or wool; Chapman 1982; Vosteen 1996; Lüning 2000), nor is there evidence that some of Lichardus' more important features make their appearance everywhere at all. In particular this is true for his tendency to link the practice of metallurgy to control exercised by emerging elites. Authors such as C. Renfrew (1978; 1986) or H. Todorova (1981, 2–13; 1991, 89, 91; 1995, 88–89) would agree that metallurgy necessitated exchange and specialised production, triggered social hierarchisation and invited attempts by higher ranking individuals to increase efficiency and stability of their power. A. Sherratt (1984; 1997), on the other hand, put much more emphasis on subsistence economy and settlement structure, giving voice to those who doubt a strong impact of metallurgy on society (see also Tringham 1991, 274–277; Kienlin 1999, 54–61).

Part of this disagreement is a result of the quite diverse phenomena designated 'Copper Age' throughout 5th to 4th millennium BC south-eastern Europe. In Bulgaria, for example, tell sites such as Ovčarovo, Golyamo Delčevo and Poljanitsa (fig. 5.4) are classified as Eneolithic/Copper Age (Todorova 1978; 1982; Whittle 1996, 81–82, 89–95; Bailey 2000, 156–160, 173–177), while in the chronological system argued for in chapter 2.1 the Eneolithic/Copper Age of the Carpathian Basin and northern Balkans only starts at the end of the Vinča sequence, i. e. after the end of the somewhat later but broadly corresponding tell settlements referred to as Late Neolithic (Link 2006; Parkinson 2006). Hence, on the one hand there are firmly integrated 'Copper Age' tell communities drawing their identity from permanent focal sites in the landscape, while on the other there is a 'Copper Age' system with only a loose network of rather impermanent settlement units (see chapter 5.3.2).

Setting aside the terminological discrepancies mentioned with regard to the denomination of 5th millennium BC tell sites, during the period in question there were undoubtedly different systems of settlement, economy and possibly social integration in various parts of south-eastern Europe.

Yet all of these were supporting a 'Copper Age' metallurgy and the production of elaborate shaft-hole implements (e. g. Bulgaria: Todorova 1981; e. g. Hungary: Patay 1984). This in itself should caution us not to draw a causal link between the practice of metallurgy and any specific kind of social organisation. Furthermore, we need to be aware that the same evidence from settlements or graves is subject to quite different interpretations depending on a given author's view of 'Copper Age' society. For example, irrespective of other organisational options, tell sites such as Poljanitsa are taken to indicate social differentiation just because there is minor variation in house size and structure, or because of order in the layout of houses and a fortification system, which is thought to require centralised power and control (e. g. Todorova 1982, 62–66, 144–165 or Chapman 1990 vs. Whittle 1996, 90–93; Bailey 2000, 156–160, 173–177). Similarly, what might appear minor differences in grave goods indicative of age, individual standing or gender may be interpreted in terms of the accumulation of wealth and hereditary status (e. g. Lichardus 1991c, 767–770 vs. Lichter 2001, 289–291, 344–349 on the Tiszapolgár and Bodrogkeresztúr evidence).

For reasons given in greater detail below the position taken here is that competition, social hierarchisation and craft specialisation during the Eneolithic/Copper Age tends to be exaggerated. Instead, an approach is argued for that may take its start from the studies of A. Whittle (1996, 72–121) and D. Bailey (2000, 153–239). Both authors are mainly concerned with Late Neolithic/Copper Age tell building communities. While slightly differing in approach they offer ways to understand these groups in terms of long-term process, the development of corporate identities and the attachment of people to their natural and built environment. Their analyses go beyond the mere search of chiefs or other leaders who had tell sites fortified or copper brought from abroad. This approach does not deny tension, differential access to social space – be it settlement or landscape –, to knowledge or items of 'expressive material culture' such as copper and gold. But it is certainly in accordance with the available evidence when it is suggested that there is no indication of a significant accumulation of personal wealth and power in graves, or internal socio-political differentiation within tell settlements. Obviously, some of the concepts advocated remain quite blurry, such as the catchall labels 'corporate identities' or 'ancestral values', but they usefully draw attention to a specific quality and complexity of the archaeological record that is not adequately covered in 'traditional' Copper Age research and discourse. Despite their interest in variability and local trajectories, however, in their specific emphasis on tell building communities both studies do not adequately account for post-tell Copper Age communities such as, for example, Tiszapolgár and Bodrogkeresztúr in the Carpathian Basin (see the passing mention made to these groups only: e. g. Whittle 1996, 72–75, 84, 107–113; Bailey 2000, 168–169, 195). A fresh approach is developed below, which examines this development in terms of another anthropologically inspired approach, namely the notion of 'tribal cycling' suggested by W. Parkinson (2002b; 2006) in order to account for the end of tell settlement and the subsequent dispersal of Copper Age settlement sites in the Carpathian Basin (see chapter 5.3.2).

However, given that Eneolithic/Copper Age social hierarchisation is controversial, it may be useful first to ask what evidence there is to support such assumptions, and how the notion of Copper Age elites came about? This is not an easy task and to narrow it down to any individual site may be to oversimplify the matter. But it is a single site, the cemetery of Varna in Bulgaria, from which much of this discussion originates (fig. 5.5; see also Whittle 1996, 75–76; Bailey 2000, 199). Its apparent evidence of hierarchisation has been subsequently extended to the whole of or at least to large parts of Late Neolithic/Copper Age Europe. For C. Renfrew (1978, 201–202; 1986, 147, 150–151, 163), in particular, Varna provided the welcome societal background to the autonomous invention of metallurgy in Copper Age south-eastern Europe postulated earlier (Renfrew 1969): "The conditions necessary for the production of such conspicuous objects of metal were clearly more readily met in a ranked society than in an egalitarian one. The precocious development of copper metallurgy in what has hitherto appeared so egalitarian a context as the Balkan copper age was thus somewhat paradoxical. Varna removes that paradox, and the evidence of the cemetery strongly supports this social view of the origins of metallurgy: copper (and gold) in Europe was first produced not for utilitarian objectives, but to fulfil the social function of conspicuous display." (Renfrew 1978, 202). The famous exceptionally rich graves, including a substantial number of cenotaphs (fig. 5.6), were interpreted as evidence of a chiefdom, and prestige goods of copper and gold assigned a central role in the process of political hierarchisation. Partly less anthropologically informed, with differences in causality and opinion on the precise mechanisms involved (e. g. control over some kind of ill-defined 'trade' vs. a prestige goods economy), this is what Varna stands for from its discovery in the early 1970s until today. The site typically stands as evidence of an (hereditary) elite, be they chiefs or just some rich 'leaders', exercising control over the production and circulation of metal objects and exchanging them with similar elites in far off countries (see, for example, Fol/Lichardus 1988; Ivanov/Avramova 2000; various papers in Lichardus 1991a).

The latter step, in particular, involves a high degree of extrapolation from the archaeological data. A recent example being L. Klassen's (2004) study on the early Neolithic in northern Europe which is explained by the acceptance of the Copper Age ideology covering large areas of central Europe (e. g. Michelsberg culture) into the Ertebølle territory (see also Thomas 1988). This explanation involves systems of elite exchange stretching as far as from Brittany to Varna (figs. 5.7 and 5.8; see also Pétrequin/Croutsch/Cassen 1998; Pétrequin et al. 2001; 2005; 2006). Despite a site like Durankulak (Todorova 2002, 270–277), however, Varna is unparalleled even in Bulgaria. Importantly, there is no comparable evidence from other cemeteries of status inherited beyond prestige

Fig. 5.5: Finds from grave 43 of the cemetery of Varna in Bulgaria (after Fol/Lichardus 1988, 59 fig. 29).

derived from age and personal achievement (Whittle 1996, 95–101; Bailey 2000, 197–203; Lichter 2001, 75–113). The famous rich cenotaphs, it has been suggested, may indicate the 'community importance' of burial ceremonies and indicate ancestral rites rather than refer to some rich and powerful leaders who went missing during warfare abroad (Whittle 1996, 97–101; Bailey 2000, 203). The rich burials rather than express individual status and refer to socially preeminent persons alone, possibly provided an opportunity to negotiate inter-individual distinctions in the context of burial ceremonies, which put equal emphasis on the "inclusion of differently identified individuals within a larger group buried within the cemetery" and community cohesion (Bailey 2000, 202, 208–209). Finally, Varna as such "may represent extra-ordinary mortuary behaviour unrelated to the reality of everyday life as documented from settlements." (Bailey 2000, 199; cf. Whittle 1996, 100). Even if the rich and powerful of a much larger area than just the surroundings of lake Varna were buried in the Varna necropolis (Renfrew 1978, 201–202; Klassen 2004, 327), this is not enough to cover the whole of south-eastern Europe, let alone all the rest of the continent. Layout and fortification of contemporary settlement certainly indicate a concern with order and some organising authority. However, this authority might have been communal, and despite claims to the contrary (e. g. Chapman 1990) there is no positive evidence from the settlements of individual or lineage competition, control exercised over any extended area, or individual power referring to more than descent groups or households (cf. Todorova 1981, 11; Todorova 1982, 62–65; Todorova 1991, 91; Lichardus 1991d, 186–187; Whittle 1996, 90–93; Bailey 2000, 190–191).

If such is the present state of affairs, we may turn to the wider field of anthropology for a hint at some possible alternative models before returning to the social context of Eneolithic/Copper Age metallurgy below. In the following paragraphs an attempt will be made at identifying and defining some themes and concepts that might help model the spread of metallurgical knowledge without reference to Copper Age elites (see also Kienlin in prep.; Kienlin/Zimmermann in prep.). It is argued that despite theoretical claims to the contrary meta-narratives and evolutionist assumptions still prevail in our search for the origins of ranking and social hierarchies. There is a 'centralisation bias' in our approaches and 'complexity' is wrongly equated with hierarchy and executive power. Undue emphasis is put on vertical political differentiation and the emergence of hierarchical systems. This leaves other aspects of the groups in question un-illuminated and assumes the existence of institutionalised, hereditary leadership when the available data can just as well be interpreted to support a variety of quite different forms of social organisation and control. We may ask here, what motivations other than just domination

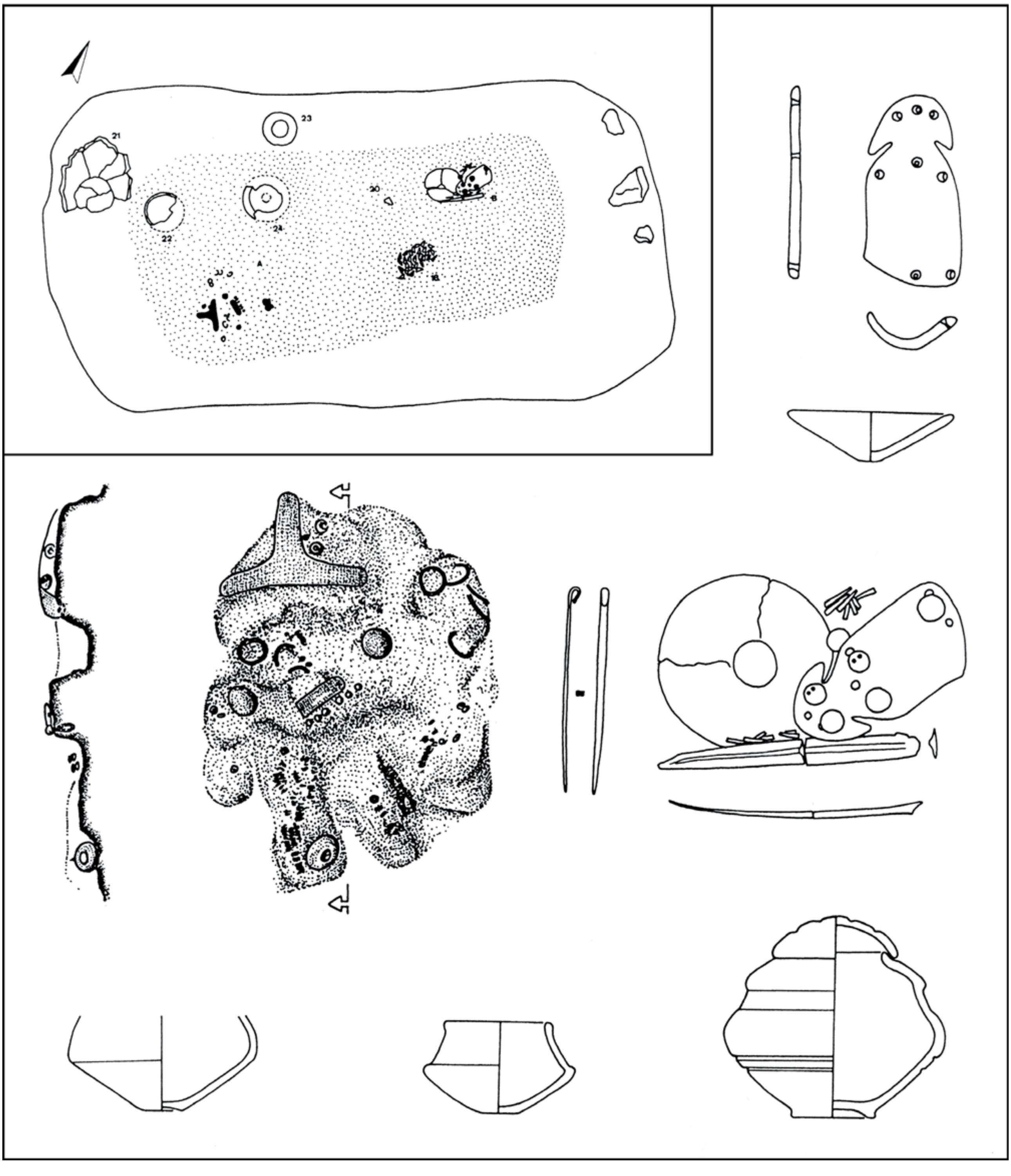


Fig. 5.6: Cenotaph grave 3 of the cemetery of Varna with a clay mask with golden ornaments, a marble idol and other 'grave' goods (after Lichter 2001, 90 fig. 35).

and aggrandisement guide human action? How do the ambitions of social actors relate to corporate strategies, and how this is negotiated in a specific cultural context by reference to the essential values of those solidarities? We need to be aware that there are many different kinds of cooperation, authority or leadership, and the 'pursuits' of collectivities such as the household, kin-groups or the tribe may overlap or contradict individual aspirations on different levels.

This is not to say that the study of elites and hierarchy is not important. For many years the interest in elites and their control over production and/or exchange has been a productive analytical focus. But we should not be looking for 'types' of political systems anymore such as in the well-known hereditary power versus achieved power debate (that is chiefs vs. Big men). Authority or political power are not a fact and they are not static. They are exercised on different levels and by different (groups of) people from

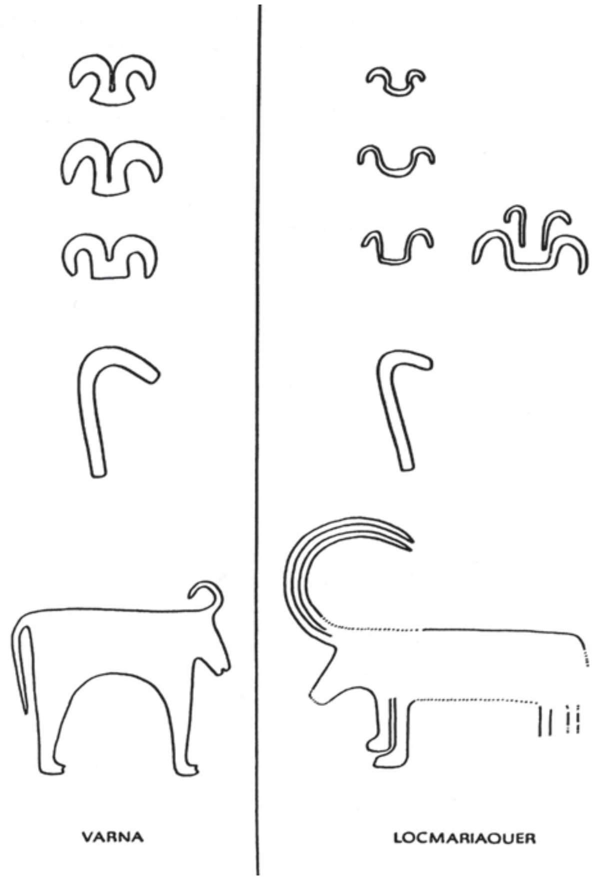


Fig. 5.7: Depictions of cattle from Varna and Brittany supposed to prove exchange between Copper Age elites (after Klassen 2004, 265 fig. 141).

the household to larger entities such as the 'tribe' or the 'chiefdom'. The principles upon which they are based may vary and their sources may be manifold. Social systems and political hierarchies are not stable. Legitimacy may be questioned, and cultural norms such as achievement or descent may be manipulated according to context. They are drawn upon both by individuals and collective groups to various ends. Irrespective of the presence of higher-order executive power or centrality we should take an interest in how the component parts of society interact and how leadership is negotiated on different levels and in different frames of reference.

5.2.1 Elites, Essentialism and the Evolution of Political Rule

The Copper Age certainly is not the only period to which such narratives apply, and much archaeological effort is directed towards the identification of hierarchies throughout prehistory and early history. Although nowadays few would overtly adhere to a notion of inevitable progress this approach still is closely linked to evolutionist assumptions on increasing cultural complexity. In past decades the search for elites has even been extended backwards in time. Where previously there were Mesolithic bands on the verge of starvation we are now talking about the social dynamics of hunter-gatherers that gave rise to agriculture and sedentism (e. g. Bender 1978; Edmonds/Richards 1998). Similarly, the European Neolithic was seen by V. G. Childe (1962) as a period of stagnation eventually irradiated by Near Eastern light. Now, since the Radiocarbon Revolution social complexity and chiefdoms in Neolithic and Copper Age groups (e. g. Renfrew 1973a; 1973b; 1986) became the favourite explanation of culture change and the emergence of Bronze Age society (Kienlin 1999). The resulting interest in elites and political hierarchisation fits in with a more traditional emphasis on the dynamics of Bronze Age society. In Anglo-American archaeology, again, this idea can be traced back to G. Childe (see Rowlands 1994), whereas in parts of Continental academia there is a tendency to see the European Bronze Age as historically unique simply due to its impressive record of bronze artefacts and the largely unchallenged notion of a significant impact of metallurgy on society (e. g. Strahm 1994; papers in Hänsel 1998; Demakopoulou et al. 1999; Müller 2002a; see, however, Bartelheim 2007, Kuijpers 2008 and papers in Bartelheim/Stäuble 2009 for a more differentiated view). Last but not least there are the well-known debates on Iron Age social complexity, on Hallstatt *Fürsten* and Celtic *oppida* as (proto-) urban settlements cut short in their development by Roman invasion (cf. Biel/Rieckhoff 2001; Eggert 2003; 2007).

The emerging picture is one of increasing social complexity – perceived from the top and equating complexity with hierarchies and political power – with Late Neolithic or Copper Age elites establishing far-reaching exchange networks, and breaking ground for Bronze and Iron Age social stratification (e. g. Renfrew 1986; Lichardus 1991a; Klassen 2004; Kristiansen/Larsson 2005; Harrison/Heyd 2007). At best attention is drawn to occasional evidence of instability, the temporary devolution of previously more hierarchical structures. But the overall direction is clear, and the evidence, mainly from graves and settlements, is studied in an attempt to establish how far on its way to a perceived aim of social stratification the prehistoric group in question had proceeded.

In a traditional vein this may take the form of identifying rich graves with some kind of rather ill-defined leaders or 'princes' (*Fürst*). Evidence of communal labour directed, for example, towards fortified settlements or Megalithic monuments is taken to imply and require elite control. Processual archaeology added methodological rigour by insisting that differential access to power and wealth should be demonstrated (by statistical methods) rather than intuitively assumed (cf. Parker Pearson 1999, 27–32; continued in approaches to social structure via *Sozialindices* of grave goods, e. g. Sprenger 1999; Hinz 2009). In addition, aspects of leadership and power were now framed in terms such as Big man or chief derived from neo-evolutionary social typologies. More recently these methods were challenged by those advocating a more advanced approach to society based on agency or structuration theory (Bourdieu 1976; 1998; Giddens 1979;

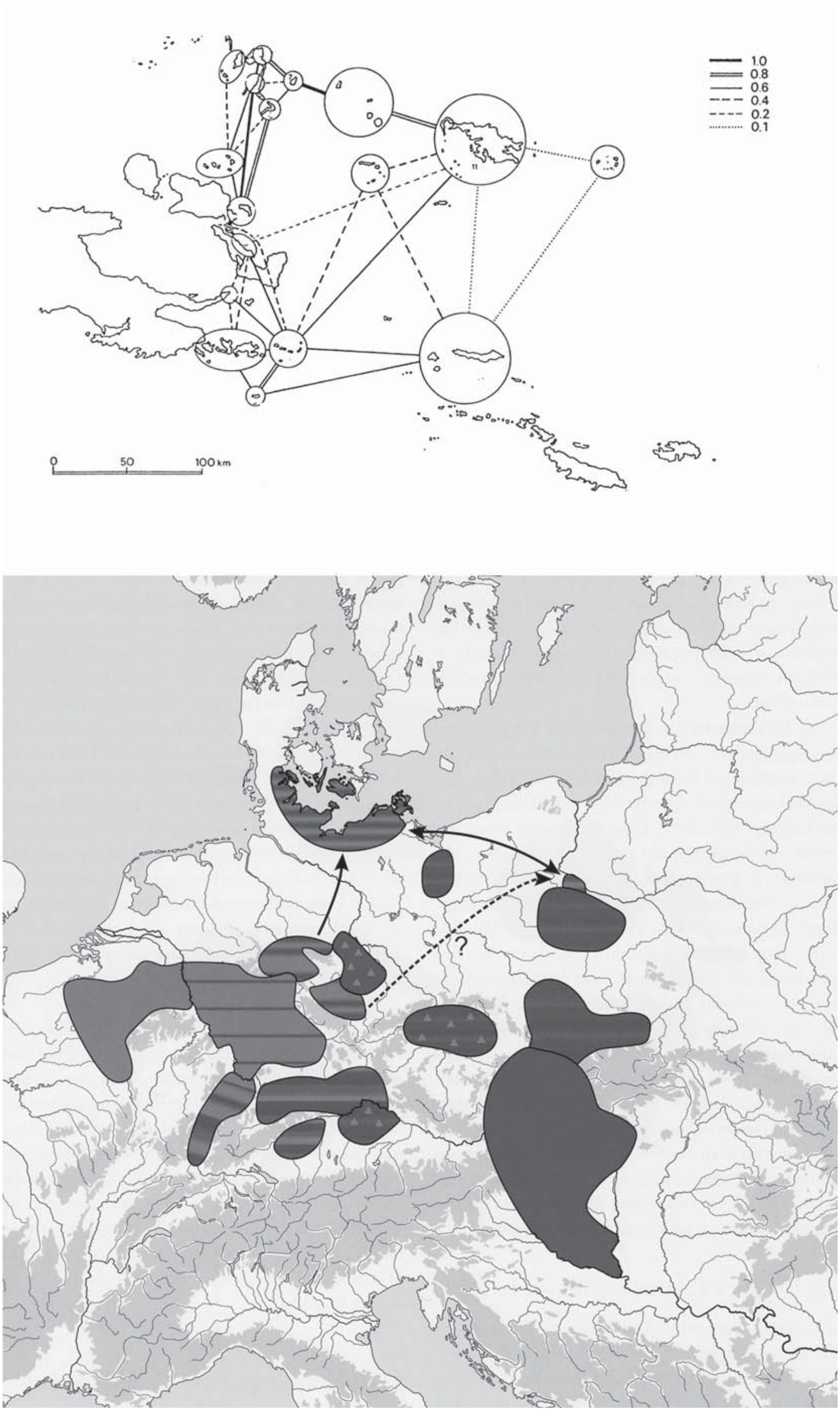


Fig. 5.8: Interaction of Neolithic/Copper Age groups and the neolithisation of northern Europe (below) – understood as the spread of a 'Copper Age' ideology and modelled on the Melanesian Kula exchange of prestige goods (above; after Klassen 2004, 289 fig. 146, 321 fig. 155).

Ortner 1984, 144–157; cf. Shanks/Tilley 1992, 116–134). Attention was drawn to variation and internal differentiation of power in political organisation (e. g. Blanton et al. 1996, 1–2, 5–6) or to resistance in opposition to domination and elite discourse (e. g. Miller/Rowlands/Tilley 1995; cf. Wynne-Jones/Kohring 2007, 4–5). In this context, too, it was asked in what ways material culture may be used to negotiate social and cultural 'reality' rather than simply reflect social 'structure' (e. g. papers in Veit et al. 2003; Kienlin 2005a; Tilley et al. 2006; cf. Kohl 2003; Hahn 2005). Such approaches are an improvement on the theoretical side because they see material culture as a dynamic, rather than static aspect of society and because it was realised that material culture can be used to manipulate and hide underlying processes. But much of this work still shares the traditional top-down approach and gets us away from asking new questions due to its focus on diversity and resistance *within* hierarchical structures (Wynne-Jones/Kohring 2007, 4), and many agency-based studies remain on the level of programmatic announcement. Often the move from structure to individual agency is accompanied by a fundamental indifference towards questions that previously constituted 'social archaeology'. Or we talk about the construction of poorly understood and ill-defined values and identities, instead of truly looking into the cross-cutting of the individual, small-scale integrative units such as kin groups and potentially higher-order forms of power.

Much theoretical work is attracted, quite naturally, by lavish finds such as Copper Age Varna on the Black Sea or the Early Bronze Age graves of Leubingen and Helmsdorf in Germany (e. g. Sørensen 2004; 2005; Chapman et al. 2006; Kienlin 2008c) that we feel sure represent prehistoric elites. Often the mundane remains of day-to-day life receive little proper attention, which otherwise might invite attempts to think about and model ancient society other than as hierarchical systems. Thus extraordinary phenomena such as the occasional 'princely' graves become our guide to prehistoric social structure. As noted by Fowles (2002, 17): "[...] in almost any archaeological context presently considered tribal, the discovery of one or two truly 'elite' burials [...] would be enough for most scholars to bump the case in question up from a tribe to a chiefdom – regardless of other evidence to the contrary."

A political interpretation is preferred when in fact burial ritual may tell us about many other aspects of belief systems and identity (e. g. Parker Pearson 1999; Kümmel/Schweizer/Veit 2008). In consequence we feel entitled to 'read' any kind of accumulation of artefacts in graves in terms of ranking. Where such lavish burials are missing we tend to argue that elites existed but were concealed for ideological reasons or there simply was no necessity for them to express their status in death (e. g. Morris 1987, 44–54, 87–96; Cannon 1989, 437–438, 444–447; Higham et al. 2007, 647–652). Elite positions are taken as a given where their existence needs to be proven by reference to contextual information. This is a legacy of the 1980s and 1990s strategic notion of ideology used to naturalize or conceal inequality (e. g. Shanks/Tilley 1992, 155–171), while in fact there is both: the potential to dominate *and* to renegotiate what appears to be given. Power understood as domination is seen as something operating largely from above, while theoretically at least there are different levels on which power and authority are exercised on an everyday basis as well as in more formal situations (Shanks/Tilley 1987, 61–78; Miller 1995, 64–65).

Irrespective of approach, be it processual, post-processual or just traditional, we tend to share a top-down perspective and an overriding interest in political hierarchies – be it in terms of elites required to organise and control collective work or in terms of inequality and unequal access to knowledge, power or resources (cf. Blanton et al. 1996, 2). Undue emphasis may thereby be put on the evolution of hierarchies, stability and longevity of social inequality. Instead, the abrupt appearance and end without follow-up of such phenomena as Varna or Leubingen may in fact point to the opposite: the inherent instability of prehistoric hierarchies, different both from what we expect from a superficial reading of ethnography and from our interest in the rise of stratified society (see below; Kienlin 2008c).

A consequence of these underlying assumptions is that our reading of anthropology and ethnography is partial as well. We tend to focus on studies and approaches seemingly in accordance with our notion of prehistoric social evolution. Leadership, competition and/or the balance of power in modular, segmentary systems, as well as any kind of informal decision-taking and community self-regulation tend to be ignored (cf. Béteille 2002, 1020–1021; Roscoe 2009, 101–105). Much more interest is directed towards formal leadership and truly political organisation (cf. Wynne-Jones/Kohring 2007, 3–4; Osborne 2007, 145), and in this field of study we touch upon such concepts as the 'chiefdom' (fig. 5.9; e. g. Service 1962; Renfrew 1973b; Earle 1997; 2002). That there are too many chiefs in archaeological research was already noted by N. Yoffee (1993), who drew attention to significant changes in their definition, the general decline of anthropological interest in such social types or formations as well as to the obvious problems archaeologists suffer in their attempt to identify chiefdoms in the archaeological record. However, the concept is still in use (e. g. Strahm 2002; Müller 2002b, 270–271; Krause 2003, 257–261), and it certainly refers to a broad region on the spectrum of human political forms. Hence, related discussions surrounding the evolution of 'Great men', 'Big men' and 'chiefs' may be taken to illustrate some important points for our present concern (for a more fundamental critique aimed at altogether disposing of such concepts see, of course, Shanks/Tilley 1987, 137–165).

The first point is a pragmatic one and refers to the inevitable delay of interdisciplinary reading. However, there is also a related unwillingness to follow through discussions once an obvious solution to ones problems has been found. In much of the earlier anthropological literature there is an essentialising tendency that first gave rise to the above mentioned 'types' of social and political systems

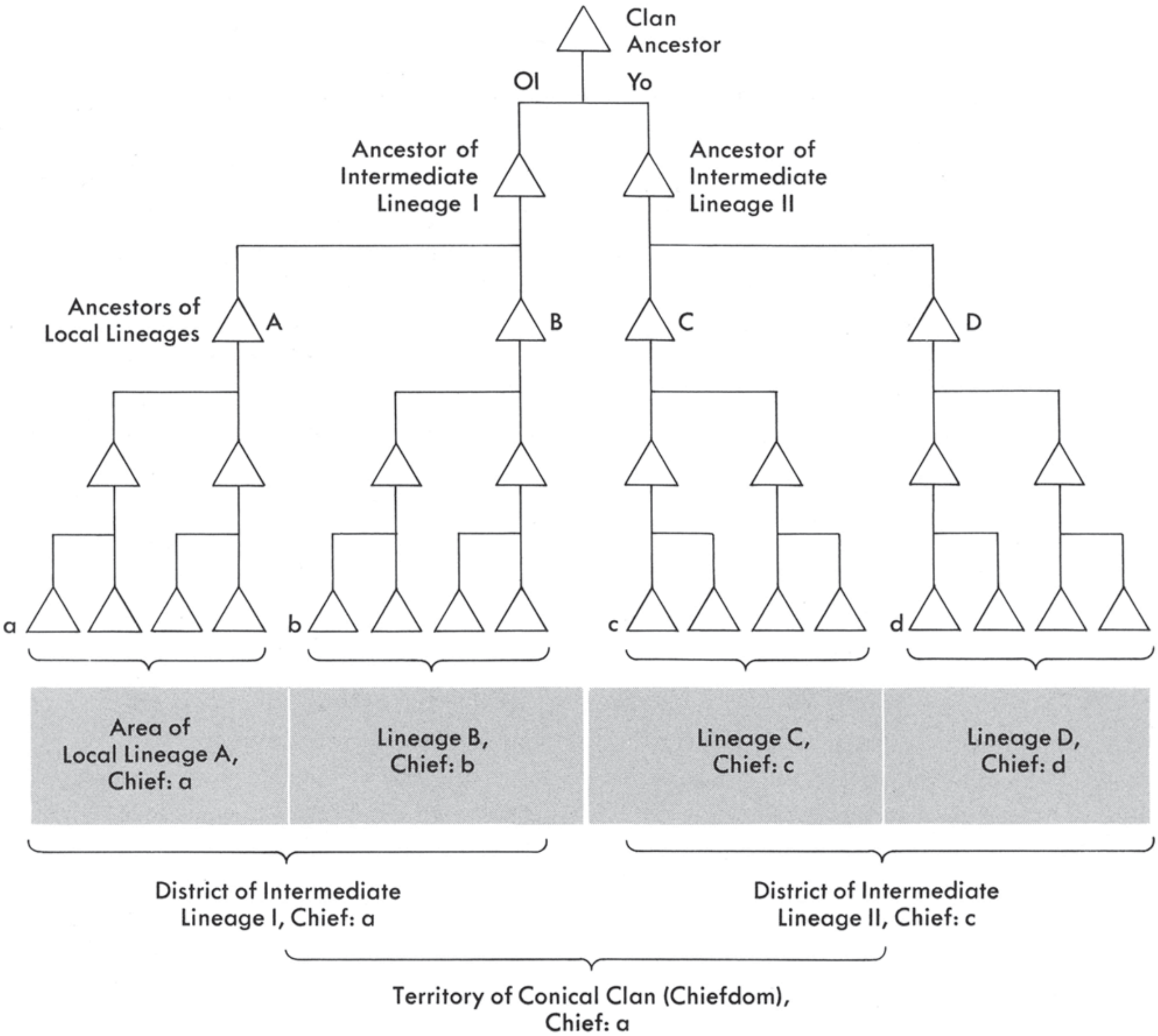


Fig. 5.9: Schematic representation of a conical clan or chiefdom (after Sahlins 1968, 25 fig. 2.2).

such as Big man societies or chiefdoms (fig. 5.10). Only somewhat later did it become obvious that, for example, redistribution may not be an important feature of chiefdoms as suggested by the original definition (Yoffee 1993, 62; Earle 1997, 75–89; see also Gregory 2002, 918–931). Similarly, M. Godelier's (1986, 162–188) scheme of Great men successful in war and 'entrepreneurial' Big men has been challenged on grounds of its rigid division of different avenues to power and the simplistic equation of both with different kinds of exchange (cf. Roscoe 2000, 94–96). In a more general vein, M. Sahlins (1963, 288–300) dichotomy of Melanesian Big men and Polynesian chiefs is nowadays regarded as stereotyping and his examples not typical anymore of the 'type' of social and political system they were thought to represent (cf. Godelier 1986, 188; Roscoe 2000, 84–87). In particular, the equation of chiefdoms with hereditary power and Big men with achieved power is seen as an oversimplification. Instead, both should be understood as strategies drawn upon by knowledgeable

Childe (1936)	*Service (1962) Johnson and Earle (1987)*	*Sahlins (1963) Earle (1978)*	*Fried (1967)*
Hunter–gatherers	Band (family level)	Head man	Egalitarian society
Farmers	Tribe (local group)	Big man	Ranked society
Civilization	Chiefdom	Simple	
		Complex	Stratified society
	State	State	State

Fig. 5.10: 'Types' of social and political systems arranged into an evolutionary sequence (after Earle 2002, 941 tab. 1).

agents: "Rather than dichotomizing ascribed and achieved leadership, it may be more profitable to view the cultural apparatus of ascription (ideologies of primogeniture, the selective transmission of spirituality or sacredness, etc.) as a cultural resource that political agents compete to control or transact, as they do other resources." (Roscoe 2000, 110).

If there are no prototypes of social systems left and reality is exceedingly complex, the implication for archaeology is not, however, to drop any attempt at working with such concepts. We should not be looking for direct analogies in prehistory of social formations that developed in a completely different historical setting (including colonial contact) anyway. But the archaeologist is obliged to develop an idea of the wide range of organisational possibilities of human societies. Beyond mere sherds or bones this is what we are doing anyway; more typically, however, we draw upon common sense rather than on any thorough analysis of discussions in disciplines concerned with contemporary human culture and society. An enduring interest – not just the occasional analogy – in anthropology and sociology may help us to a better understanding of the flexibility of what we think of as 'structure' and its relation to human agency.

5.2.2 Social Dynamics and the Explanation of Culture Change

An obvious answer to the question why we are so comfortable with the emergence of ranking refers to the role of social and political hierarchies in the explanation of culture change; more precisely the role of ranking and elites both as a cause and outcome of evolutionary progress. Technology in the widest sense, including subsistence strategies, develops towards the 'better', and this development is thought to involve managerial competence and/or aggressive 'Triple A' personalities (Hayden 2001, 30; cf. Gilman 1981, 4–8). People capable of drawing on surplus products and/or symbolic capital derived from it to aggrandise and accumulate wealth and power. Again, this notion is confirmed by a superficial reading of anthropology, many of whose concepts were – initially – arranged in terms of evolutionary progress and the succession of different 'types' of production, exchange and political organisation. This is, of course, a specific approach, and it involves a general acceptance of increasing complexity and the evolutionary succession of different social systems. This outlook also entails a political approach to complexity and carries with it some specific assumptions on the sources of power, namely the economic foundations of hierarchical systems.

Much of this is in good accord with what archaeologists think anyway; still it falls short of some more recent developments. Anthropological discussion, as usual, is more complex than selective reading implies. First of all, some would claim that chiefdoms in other parts of the world are not analytically distinct from Big men systems since power ascribed and power achieved are a continuum of organisational options rather than a dichotomy (Roscoe 2000, 107–110). Secondly, there are long-lasting discussions as to which direction evolution actually takes (cf. Roscoe 2000, 99): from Big man to chief? Or may chiefs decline to Big men? And do chiefdoms by their hereditary social inequality really qualify as precursor of the state from an evolutionary perspective (Yoffee 1993, 65)? Chiefdoms, to be honest, from the widely quoted Hawaiian perspective are cyclical (e. g. Earle 1997; 2002; cf. Yoffee 1993, 62). However, a third and most important point refers to the underlying assumption "that social systems have internal dynamics responsible for change" (e. g. Earle 2002, 949), the political arena is "intensely competitive" (Earle 2002, 957), and the potential to accumulate economic power by control over staple foodstuffs and/or prestige goods is in principle unlimited (Earle 2002, 940, 956). I don't want to press this point, but support and resources drawn from close kin are limited (Earle 2002, 951, 956); threat and intimidation, military power and physical force are conceived of as difficult to control (Earle 2002, 951–952, 956); ideology and tradition may also be used to challenge domination (Miller 1995, 66–68; Earle 2002, 952, 956). So where are the dynamics supposed to originate from when – in the wider domain of economy as well – (chiefly) assertions on land may be avoided by mobility, and feasting or (ritualised) exchange may refer to communal values and/or reproduce the *status quo*, instead of lending themselves to manipulation by individuals (Blanton et al. 1996, 4; Roscoe 2009, 94–99)?

A similar criticism was advanced towards 1980s and 1990s neo-marxist readings of prestige good systems, taken in their widest sense to include ritualised exchange, control of elders over knowledge involved in production and ritual (e. g. Friedman/Rowlands 1977; Braithwaite 1984; cf. Mauss 1990; Godelier 1999). Asymmetry, attempts at oppression and aggrandisement are perceived as ubiquitous while ethnographically stability and the reproduction of existing structures may also be the result (Shennan 1987, 370–372; Mays 1995, 220–223; Kümmel 1998, 131–132, 159–162). Of course, this is not to say, that power may not be derived from any of these sources, but it is not proven that hierarchies emerge whenever they are present. Things are more complex than our concern with the emergence of political leadership has us believe. Motivations guiding human action and strategies are manifold. They are negotiated in a specific cultural context. There are different kinds and levels of authority or leadership, and the aspirations of any of these 'leaders' are knitted together on various levels with the 'interest' of collectivities such as the household, kin-groupings or the 'tribe'.

Feasts are prime examples of "[...] the arenas of social action in which, and the sets of practices by which, the micropolitics of daily life are played out" (Dietler 2001, 66). They may involve anything from two to thousands of people (fig. 5.11). They serve to promote intra-group solidarity, establish alliances and allow inter-group cooperation as well as competition, the quest for dominance and the attempt of elites "[...] to crush their rivals with hospitality" (Dietler 2001, 77). Most if not all of these can be said to involve

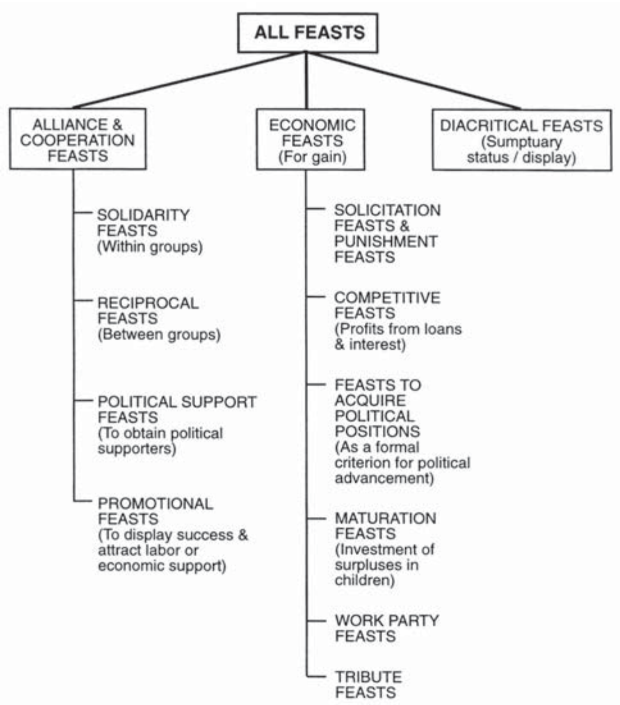


Fig. 5.11: Types of feasts (after Hayden 2001, 38 fig. 2.1).

'commensal politics', 'empowering' (Dietler 2001, 75–85) and "[...] the strategic reciprocal conversion of economic and symbolic capital toward a wide variety of culturally appropriate political goals" (Dietler/Hayden 2001, 13). But we need to be careful not to focus on just one goal, i. e. political domination, or mistake any of these notions as an explanation of culture change. They may easily become a welcome mechanism providing us with the dynamics we are in need of within a prehistoric society we think is evolving towards social ranking. Feasts "[...] *can* serve as mechanisms for the transformation of informal power into institutionalized formal political roles [...]", and they "[...] *can* result in spiralling asymmetries [...]" (Dietler/Hayden 2001, 17; italics added). But an individual's self-interested political action may be checked by culturally prescribed sets of rules. Moreover, 'self-interest' may be closely tied down to the 'success' of larger social entities operating on various levels (Dietler/Hayden 2001, 13; Hayden 2001, 29–35; Roscoe 2009). Competitive or even agonistic feasting, that is to say, is just one possible aspect of a wider set of practices to negotiate and organise the social that also serve to reproduce social units, reaffirm kinship ties or *maintain* one's position among peers (Hayden 2001, 35–42, 44–45, 53–59; Dietler 2001, 68–80). Feasts "both unite and divide"; they provide a "repertoire of forms of political action" to be drawn upon by different actors – individual or collective – to different ends (Dietler 2001, 77, 93).

5.2.3 Kinship, Tribes and Cooperation

Kinship studies were central to classic early to mid-twentieth century anthropology, but subsequently went into decline due to their heavy emphasis on the structure and the formal logic of classificatory systems and kinship terminology (Barnard 2002; Carsten 2004, 10–26). Much of this, the linguistic side in particular, is beyond the reach of archaeology. Still, kinship is a basic principle along which human society, past and present, is organised. We need to be aware of both some of the basic concepts involved and the development of kinship studies including some of the more recent reformulations of this field of investigation (e. g. Carsten 2004).

Kinship is a profoundly cultural notion (Barnard 2002, 784–789). That is to say we are not or not exclusively concerned with biological 'facts' here, but with "[...] the ways in which certain relationships come to be 'culturally constructed' as relations of kinship by virtue of their grounding in an indigenous biology of shared substance." (Ingold 2002, 742). Kinship comprises (social) parenthood, rules of descent and residence, the transmission of knowledge and property from one generation to the next – aspects of group structure and formation covered by descent theory – as well as alliance established through marriage. The latter branch of kinship studies or alliance theory concerned with the relations between groups was established by C. Lévi-Strauss (1981 [1949]), who added the important notion that marriage can be conceived of as a kind of 'gift' exchange of sisters/daughters by brothers/fathers, and on this basis developed his distinction between 'elementary' and 'complex' structures of kinship (Barnard 2002, 802; Gregory 2002, 925–927; Carsten 2004, 12–13).

In consequence of genealogical branching beyond the nuclear or extended family in kinship-based societies there are wider networks linking individuals on the basis of common descent, real or fictional, without being members of the same household or even living in the same village. Larger entities such as segmentary tribes or chiefdoms are thought to be composed of such descent groups, lineages or clans (e. g. Sahlins 1963, 287–288; 1968, 14–27, 48–73; cf. Eggert 2007, 259–269). If kinship from this perspective can be said to form the backbone of social and political structure (Barnard 2002, 784; Carsten 2004, 10), we should naturally be interested in such concepts. It will be suggested below that we may find rudimentary evidence of such structures in Neolithic, Eneolithic/Copper Age and Bronze Age settlements and cemeteries. Aspects of prehistoric technology, such as the spread of metallurgy, may also be understood in terms of non-verbal learning and communication of metallurgical knowledge along kinship lines in segmentary Late Neolithic/Eneolithic society.

Things are not all that easy, however, and we have to turn to some of the limitations of classic kinship theory in order to refine our approach. First, some of the concepts involved are 'types'. They are the result of essentialising from a more complex reality, and they were conceived and arranged into chronological order in an evolutionary intellectual climate (see above for a related point on older chiefdom literature). Second, much of past scholarship focused on formal structures and the logic of culture and society rather than on the impact notions of kinship have on reality. Broadly

speaking clans and subclans, lineages and sublineages may not have any significance for people's daily lives. 'Prescriptions' such as marriage rules may have little impact on 'practice', the actual behaviour of individuals mating (Barnard 2002, 802–803; Carsten 2004, 11–12; Roscoe 2009, 75–77). Kinship, as stated earlier, is not a biological fact and is not static. It is a set of cultural norms that may be drawn upon according to context. Descent may be controversial and manipulated, and it may not be the only organising principle in action.

There are several implications of this approach. On a local scale, for example in looking at burial evidence, it is likely that descent had a role to play in structuring prehistoric communities, and it was part of their underlying principles. But this is descent in its wider and flexible cultural sense, including expansive strategies such as marriage/alliance, the 'acquisition' of children and in fact adults; or, as far as craft is concerned, apprentices from outside the nuclear family or indeed the immediate kin group. Furthermore, alternative concepts need to be considered such as a grouping into reproductive, subsistence and defence groups recently suggested for New Guinean society. Operating on different levels of integration and directed at different tasks, such groups may or may not correspond to society perceived in indigenous terms of (ideal) kinship (Roscoe 2009, 77–88).

Second, larger entities such as tribes or chiefdoms may be composed of descent groups such as lineages or clans. Irrespective of the presence of higher-order executive power or centrality we should take an interest in such component parts and explore how they are integrated and relate to society as a whole. For this will not be a static relation, and the conventional interest over who was 'top dog' clearly falls short of an adequate representation of the social dynamics of prehistoric society. Political leadership, if any, in such systems may not be stable. The principles upon which it is based may oscillate between ascriptive and achieved, and the sources of power may be manifold, for instance wealth-based or knowledge-based. The same, of course, will also apply to the component parts of larger groupings. Lineages or clans may be egalitarian or ranked with regard to such different concepts as economic success or ritual knowledge. They cooperate or compete on various occasions and on diverse matters, and so will any other corporate groups present (Sahlins 1963, 287; 1968, 8–13; Blanton et al. 1996, 3–4; Roscoe 2009, 94–105).

We should not be trying to identify this or that 'type' of kinship system; we are confronted with the material remains of the reality of complex ancient life, which was most likely different in some aspects from the ethnographic present. We are not studying the remains of ancient kinship *per se* but the remains of a past "human discourse on social relationships" drawing on, amongst other factors, culturally specific notions of kinship (Ingold 2002, 740). Competing frames of reference (such as kin vs. defence groups; Roscoe 2009) and individual departure from "the rules of the game", both strategic and unpremeditated, result in variability that in itself is of interest. But there is also patterning defined by past action guided by prescription. We are not reduced to and should not study individual agency as if it was "divorced from the kinds of social institutions that anthropologists had previously bracketed under kinship" (Carsten 2004, 20; cf. Wynne-Jones/Kohring 2007, 5).

Tribal society, just like kinship, is a concept that might help us explore groups in which we suspect permanent ranking is absent (fig. 5.12). Tribes, of course, just like kinship have been done away with in most recent anthropological literature; but against this tendency I would like to refer to a recent reappraisal of the 'tribe' (Parkinson 2002a; Fowles 2002), and go on asking why such collectivities should occur and why individuals or small groups should co-operate and take part in collective action at all (Roscoe 2009).

The concept of tribe goes back to 19th century anthropology and sociology, for example the work of L. H. Morgan (1871; 1901; 1964) and E. Durkheim (1992). It features prominently in some neo-evolutionary schemes such as E. Service's (1962) succession of band, tribe, chiefdom and state (see also Sahlins 1961, 323–327; 1968, 1–13). Since then it was constantly redefined in terms of its internal structure, the mechanisms of integration and the presence of political leadership, up to the point of being conceived as meaningless (cf. Parkinson 2002a, 3–7). In particular, it was M. Fried (1968, 11–18; 1975, 1–10, 88–114) who claimed that tribes were not analytically distinct from bands in his overarching category of egalitarian society, and that tribes only occurred upon contact with complex societies, that is states. Focussing attention on differential access to status positions, the basis of Fried's (1967) own evolutionary scheme, tends to bypass what traditionally was and nowadays is considered characteristically tribal, namely 'segmentation' and 'mechanical solidarity' in Durkheimian terms (Durkheim 1992, 118–161; see also Parkinson 2002a, 2–3, 8; Fowles 2002, 14–18; Ortiz 2002, 903–904; Earle 2002, 944–945). Tribes, under this view, consist of social segments, autonomous and alike in economic and political terms. Related discussions centre on the question if there is an added value over bands, how integration is achieved and order maintained, as well as which kinds of decision-taking and political leadership may be found in tribes. To E. Service (1962) and Sahlins (e. g. 1961, 323, 326, 341–343; 1968, 1–13), for instance, the answer clearly was yes, the tribe is more than the sum of its parts. Ethnographically in tribal society there are pan-tribal integrative institutions or mechanisms such as age-grades, sodalities, religious societies, feasting and/or collective labour efforts which cross-cut constituent lineages, reaffirm a common identity and prevent fission (Parkinson 2002a, 5–8).

Such informal arrangements may or may not be stable and integration could be achieved by very different means. But when it comes to the alleged tendency of tribal society towards disunity (cf. Parkinson 2002a, 8) we should bear in mind that this concept was originally conceived as an intermediate stage in evolutionary schemes. Leaving behind us such evolutionist notions, tribal stability is possible

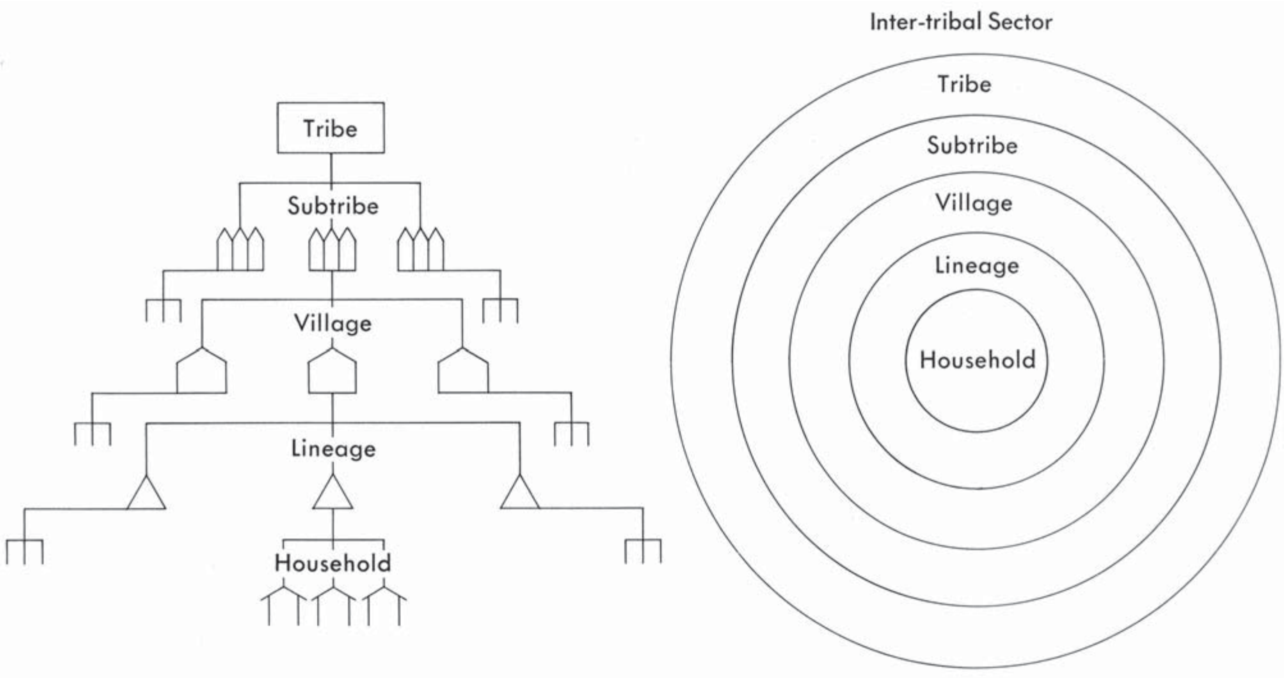


Fig. 5.12: Schematic representation of tribal society (after Sahlins 1968, 16 fig. 2.1).

despite the absence of fixed institutions or permanent political leadership. The same holds true, for example, for the mobilisation of a considerable work force towards 'conspicuous performance' or 'conspicuous construction' on the basis of situational, consensus-based decision-taking (Fowles 2002, 15–16; Roscoe 2009, 95–99). This clearly is a model for the construction of Neolithic monuments, Late Neolithic/Eneolithic tell sites or Bronze Age fortifications without 'chiefs' being involved. However, we have to dwell on the question of political leadership in tribal societies for a moment. Segmentary features are present in most other societies as well (Fowles 2002, 18); and Sahlins (1968, 20–27), on the other hand, tended to conflate everything from truly segmentary to chiefdom under a wide notion of 'tribe', which provoked some of the fundamental criticism towards this concept mentioned earlier (cf. Parkinson 2002a, 6).

With the previous discussion in mind, the obvious answer is that we are asking the wrong questions. Since leadership achieved and leadership ascribed are just the opposite ends of what in fact is a continuum of organisational options (see above; Fowles 2002, 16–17) we should not expect tribal society to link up with any specific 'type' of political leadership. Rather, it is the specific flexibility of tribal social organisation that is emphasized in current approaches, including the emergence of situational leadership that might in times of crisis come to resemble chiefdoms and extend over several generations. The point is, Fowles (2002, 20) argues, that we need to distinguish between "(1) the elements of a formal social system that may be continuously preserved and (2) the organisational options within that system that may change with ease and without significant ramifications to the underlying nature of the system itself." A convincing example of this approach will be discussed below (see chapter 5.3.2) – W. A. Parkinson's (2002b; 2006) study of the Late Neolithic to Copper Age transition in the Carpathian Basin in terms of such 'tribal cycling'. To put it in other words once more: tribal society is not static nor is there any compelling evolutionary trajectory towards either fission or fusion, towards relapse into even more decentralised structures or increasing complexity in political terms. Tribes are not deficient in that there is no fixed political structure, but there is "[...] fluidity, conflict, fission and fusion and 'push-pull' dialectical relationships between sectional (including individual) and communal interests" (R. Chapman 2007, 15). We may draw upon this flexibility to "[...] break apart the essentialism of classic neoevolutionary types." (Fowles 2002, 18).

Tribes, it has been argued, provide stability vis-à-vis environmental unpredictability and change (e. g. Braun/ Plog 1982, 505–509), or they are thought of as an adaptation to frequent aggression (e. g. Roscoe 2009, 80–88). Still, they are composed of individuals and groups who might opt out or pursue different interests on various levels. The question then remains how conflict is resolved or avoided – in the absence of mediation or sanction by a central authority – without fission or resort to violence? Segmentary systems, Roscoe (2009, 75, 89) argues, are not arranged into hierarchical levels of decision-taking with an increasingly smaller number of people involved and communicating decisions 'downwards' their respective networks. Instead, they form a nested, modular structure with people involved and cooperating in various groupings of different scale adapted to and directed towards specific types of collective interests – the above mentioned reproductive, subsistence and defence groups. He suggests

that conflicts that arise from multiple involvement and outcome intended (e. g. cooperation in terms of defence but rivalry with regard to reproduction) are negotiated by 'social signalling'; that is by reverting to 'symbolic' or 'ritualised' fighting to communicate strength and settle dispute by assessing the likely outcome of actual violence (Roscoe 2009, 72, 89–90): "If the deployment of military strength as lethal violence was a means of protecting and advancing individual and group interests vis-à-vis enemies *external* to a security structure, an honest display of fighting strength was a means of protecting and advancing the same interests *within* the structure and between allied structures without imperilling collective interests in security and peaceful relations." (Roscoe 2009, 90).

The importance of warfare in New Guinean society may limit the applicability of this example to much of European prehistory. But the mechanisms involved, 'conspicuous distribution' (e. g. 'fighting with pigs'), 'conspicuous performance' (ceremonial acts with elaborately choreographed singing and dancing) and 'conspicuous construction' (e. g. the erection of monumental spirit houses) certainly are of wider relevance (Roscoe 2009, 95–101; see also Hayden 2001; Dietler 2001). They are widely quoted in archaeological literature as well, typically focusing on their importance for the emergence and reproduction of political leadership. What tends to be neglected is the group-oriented nature of such activities and the wide range of potential 'participants' from individuals to subgroups or groups. Clans, moieties, villages, age groups or religious societies may be involved in conspicuous performance or construction, claiming and negotiating their strength in relation to rivalling groups of the same nature and size (Roscoe 2009, 95–99). "Accumulators, aggrandizers, or achievers, managers, despots or reciprocators" (Roscoe 2009, 106), to name just some of the individuals potentially trying to become more equal than others, may also be involved. But the overall 'incentive structure' may be such as to motivate "[...] individuals to contribute as much as they could to the strength of the reproductive, subsistence, and security groups and structures to which they belonged." (Roscoe 2009, 102; cf. Miller 1995, 68–75). Not all that is competitive is related to individual aggrandisement; nor is any system in which social signalling is employed to mediate cooperation, dynamic in terms of political evolution.

5.3 The Social Context of Early Metallurgy: Regional Trajectories

5.3.1 Social Evolution at Varna?

If Varna is not a suitable model for Eneolithic/Copper Age society throughout south-eastern Europe (see chapter 5.2), and is best understood in terms of 'extra-ordinary mortuary behaviour', the mediation with the ancestors and the expression of differences in individual identities in 'communally sanctioned and valued ways' (e. g. the ability to provide hospitality or to fulfill symbolic/religious roles on behalf of the community as a whole; Whittle 1996, 97–98; Bailey 2000, 199–209), there is yet another point that requires special attention: The short-lived nature of the Varna phenomenon that is mirrored by much later Early Bronze Age 'princely' graves such as Helmsdorf and Leubingen in central Europe, which occur discontinuously and only cover a few generations (Höfer 1906; Größler 1907; Becker/Krause/Kromer 1989; Rassmann 1996; cf. Sørensen 2004; 2005; Kienlin 2008c). In both cases the evidence is taken to suggest the evolution of political hierarchies and the stability of differential access to power and wealth (Copper Age: e. g. Renfrew 1986; Todorova 1991; Bronze Age: e. g. Knapp 1999; 2001; Strahm 2002; Bertemes 2004), while at face value it suggests otherwise. In terms of conventional Bulgarian chronology the Varna group is right at the end of the Eneolithic/Copper Age sequence (Todorova 1978; 1981, 2–3 fig. 1). In fact the 'climax' Copper Age society seems to have been an outgrowth of earlier developments that were inherently unstable rather than indicating a new stage of social evolution.

Instead of relying on historical concepts or contingent events to explain its end, such as an invasion from the steppes or climate change (e. g. Todorova 1981; 1995; cf. Taylor 1999), we may have to admit that our approaches fall short of reconstructing a more complex ancient reality. With the numerous cenotaphs in mind as possible indicators of cult and culture rather than just graves reflecting social hierarchies, we may miss the point in our search for chiefs, great men or dominant lineages – both in Varna and in its wider south-eastern European context. Instead we may have to turn to an approach focusing on aspects of identity, both individual and communal, constructed via burial ritual (see above) and its hypertrophic elaboration in just some historically specific situations of culture change and regional contexts such as on Lake Varna. An approach, that is to say, that does not extrapolate from Varna to the social structure of the south-eastern European Eneolithic/Copper Age as a whole, but instead seeks to understand Varna as a specific expression or reaction to broader patterns of change (fig. 5.13). A key example is the shift in the perception of death in relation to the built environment that is evident from the increasing use of extramural cemeteries during the Eneolithic/Copper Age. This represents a rearrangement of landscape use and perception and/or the construction of settlement/village identities (Parzinger 1993, 297–301, 313–320; Whittle 1996, 86–96, 101–101, 112, 120–121; Bailey 2000, 156–177, 190–209; Lichter 2001, 75–132).

Obviously, this is not the answer typically given, and we may turn to the recent studies on the absolute chronology of the Varna cemetery for some of the shortcomings of a more elite-centred approach. Based on traditional chronology and typology previously it was thought the Varna graves can be assigned to the end of the Copper Age sequence in Bulgaria (Kodžadermen-Gumelniţa-Karanovo VI) and date to the last phase III of the so-called Varna group (Lichter 2001, 87–113). Instead radiocarbon dating has shown that Varna is by one to two centuries older than expected (c. 4560–4450 cal BC), and in absolute terms runs parallel with Middle

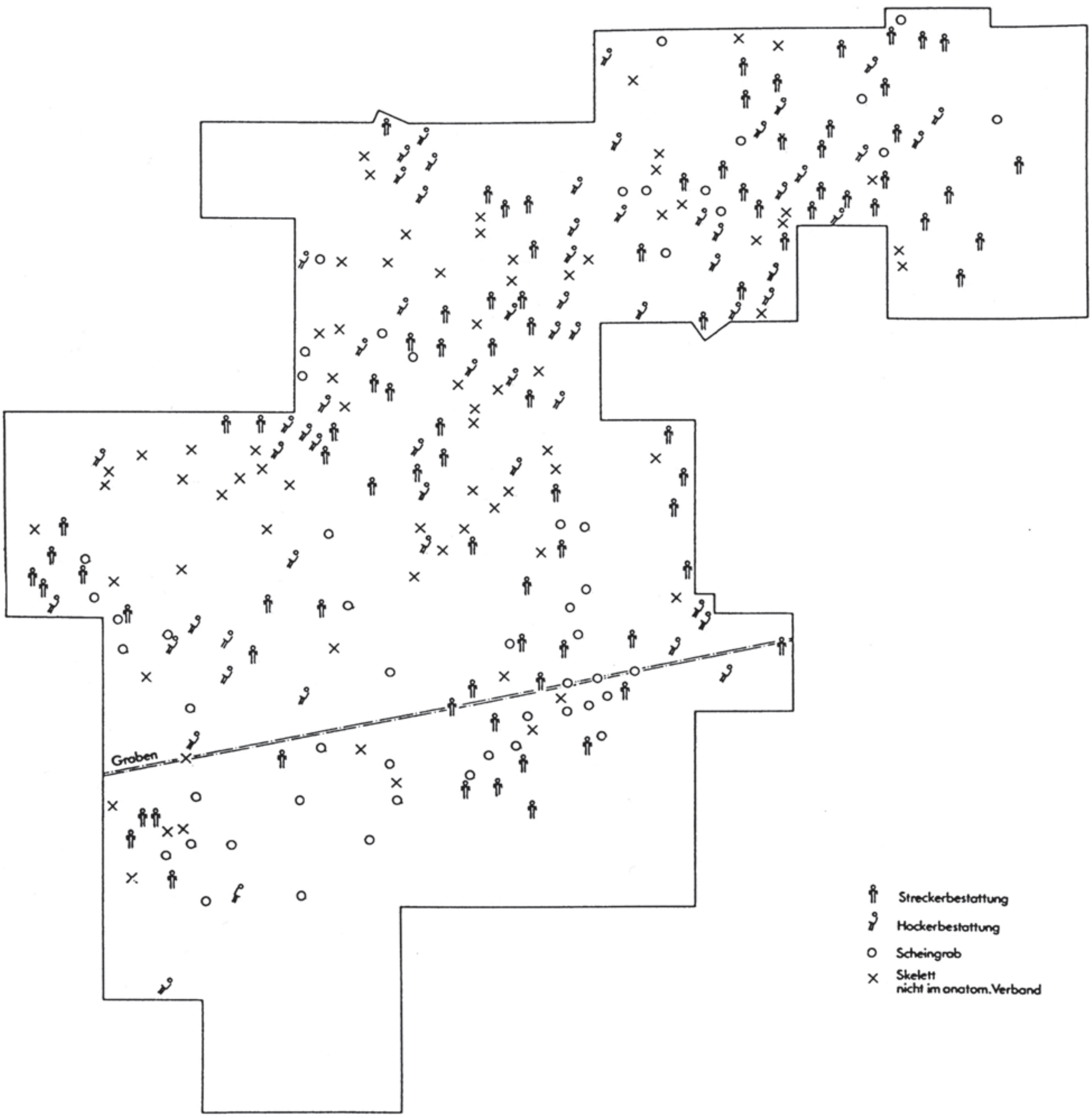


Fig. 5.13: Plan of the Varna cemetery (after Lichter 2001, 109 fig. 50).

Eneolithic/Copper Age sites in surrounding areas (Chapman et al. 2006, 165–170; Higham et al. 2007, 643–647). It is suggested that this finding may be explained by the role of Varna and the Lake Varna area as a 'centre of social and cultural innovation' (Chapman et al. 2006, 171), where new ways to negotiate status by the massive accumulation of prestigous objects in burial ritual first occurred, which subsequently found wider acceptance and spread into neighbouring Middle to Late Eneolithic/Copper Age groups (Chapman et al. 2006, 170). In support of this interpretation attention is drawn to the finding that the rich Varna graves are now thought to cover a relatively short period at the beginning of the cemetery (Higham et al. 2007, 647–651). It is assumed that newly emerging elites from several communities buried their dead in the Varna necropolis "with early elite graves creating the momentum for a successful inter-regional social network", that linked up elites and eventually resulted in the regional paramountcy of 'great men' (Chapman et al. 2006, 177; Higham et al. 2007, 650).

Now, J. Chapman's and his collaborators' approach to Eneolithic/Copper Age society is elaborate (e. g. Chapman 2000; Chapman et al. 2006, 162–165, 171–177; Higham et al. 2007, 647–652), and there certainly were different 'kinds' or 'types' of persons in command of complementary skills. However, many of these facets of personhood such as the crafting of tools or pottery, agriculture, herding or hunting would appear to have been present in earlier Neolithic society as well. The same applies to the exchange of sought-after raw materials over large distances such

as some stone or flint varieties valued for their superior properties in working and use as well as for their colour (e. g. Zimmermann 1995; Gronenborn 1997; Mateiciucová/Trnka/Götzinger 2006; Ramminger 2007). Corporate or limited interest groups too, such as age-sets, household units or kin groups such as lineages or clans, were already present in earlier Neolithic society (e. g. Lüning 2005; Frirdich 2005). So interpretation comes down to the question whether during the Eneolithic/Copper Age there was a leap forward in terms of intra-group tension and competition for individual status? Conflict and individual identities, it is suggested, could not be accommodated, negotiated or expressed any more within the constraints put upon social practices in contemporaneous tell settlements (Chapman et al. 2006, 163, 171), and consequently lead to a decoupling and spatial separation of mortuary space: "[...] a crisis in the communally accepted form of personhood and a threat to the egalitarian basis of ancestral dwelling on the tell from a new level of conspicuous, competitive consumption that could not be contained within the traditional ancestral domestic arena. [...] that led to the co-emergence of a new arena of social power to validate the newly developed patronal roles [...]" (Chapman et al. 2006, 174).

With extramural cemeteries close to a number of Bulgarian tell sites there certainly was a rearrangement in the relation of mortuary space and the built environment of the living (e. g. Golyamo Delčevo; Todorova 1982, 59–61; Parzinger 1993, 315–318; Whittle 1996, 95–96; Bailey 2000, 197–203; Lichter 2001, 114–129). In the graves there is a concern with aspects of personhood and individual identities – not least perhaps in terms of ones 'qualification' to represent ones community in extramural inhumation at all – that were not previously expressed in this way. But it has been shown that this concern typically centred on categories of age and gender – children versus adults, male versus female, differentiated by the deceased's bodies position/orientation and grave goods –, and there is little evidence to suggest a markedly stratified society beyond maybe personal merit, experience or preferred activities (Whittle 1996, 95–96; Bailey 2000, 197–203, 208–209; Lichter 2001, 125–132). Rather, in such 'patterns of similarity' and the adherence to more or less strict rules of inhumation reflective of age and gender one may see an extension of the community of the living, an emphasis on ancestors and communal values similar to that expressed by the sense of place evident from tell settlement as well as by the symmetry and order of settlement layout. Extramural burial may thus be a consequence of changing perceptions of death and its appropriate treatment rather than of social change. It may have provided an opportunity for the expression of individual distinctions. Yet it did so without negating or eroding communal solidarity, and burial grounds may have provided alternative focal points to house and tell in the landscape for ceremonies strengthening the bond between the living and the dead (Whittle 1996, 95–96,100–101, 112, 120–121; Bailey 2000, 199, 202–203).

In any case, Varna, and to a lesser extent Durankulak, continue to be exceptions rather than the rule, therefore it is difficult to see them as the origin of a pattern of social competition that spread to their Late Eneolithic/Copper Age surroundings (fig. 5.14). For Varna itself the dynamics of social change postulated are entirely conventional; a prestige goods system that supposedly led to patron-client relations on the local scale and to the emergence of Great men on an inter-regional level through access to gift exchange and the manipulation of exotic (copper and gold etc.) objects of social and/or ritual importance (Chapman et al. 2006, 171–176). Within this framework or approach the cenotaphs (see fig. 5.6) essentially remain unaccounted for except as a result of contingent historical events. Obviously, in the meantime there are (too?) many 'ancestors' in archaeological research (Whitley 2002), and loose reference is often made to identities of various kinds. But it is certainly worthwhile considering that the cenotaphs are related to some kind of communal (ancestral?) rites that took place within the precincts of the burial ground rather than just replacing the missing bodies of those rich and powerful leaders that went missing abroad (Whittle 1996, 98–100).

Similarly, it is worthwhile to dwell on the Childean analogy suggested to account for what now appears the early end of truly elite burial at Varna (Chapman et al. 2006, 172; Higham et al. 2007, 650–651): The explanation offered is that the rich burials reflect initial competition for elite positions while their decline is due to a more stable social structure later on. This conclusion is in line with both V. G. Childe (1945) and modern reformulations on this topic that burial ritual offers an arena for the negotiation of social relationships and grave goods may either express or conceal social structure (e. g. Hodder 1982; Parker Pearson 1999). Similar points were made for prehistoric groups widely dispersed in space and time – both by authors inspired by theoretical approaches to the archaeology of death and burial and colleagues who are not (e. g. Winghart 1999 vs. Clausing 1999 on early Urnfield culture elite burials, their subsequent decline and the continuity of archaeologically invisible elites; cf. Primas 2008, 76–77).

There is a problem here however, as we have gotten used to arguing that existing elites were concealed for ideological reasons or that there was simply no more necessity for them to express their status in death. A social interpretation is preferred, and elite positions are taken for granted where their existence should actually be proven by a contextual approach. If Varna was the centre of innovation for the emergence of hierarchical society this has left hardly any traces in the archaeological record of its surroundings, and there was no follow-up during subsequent periods. J. Chapman himself refers to social tensions that set an end to the burial tradition at the Varna cemetery (Chapman et al. 2006, 176). He allows for an alternative discourse established in the 'poor' Varna graves that supposedly denied "... the dominant values sustained by accumulation and the consumption of exotica in favour of the less spectacular values underpinning fractality." (Chapman et al. 2006, 173). He is somewhat unclear on the survival of both the supra-regional exchange in prestigious objects and/

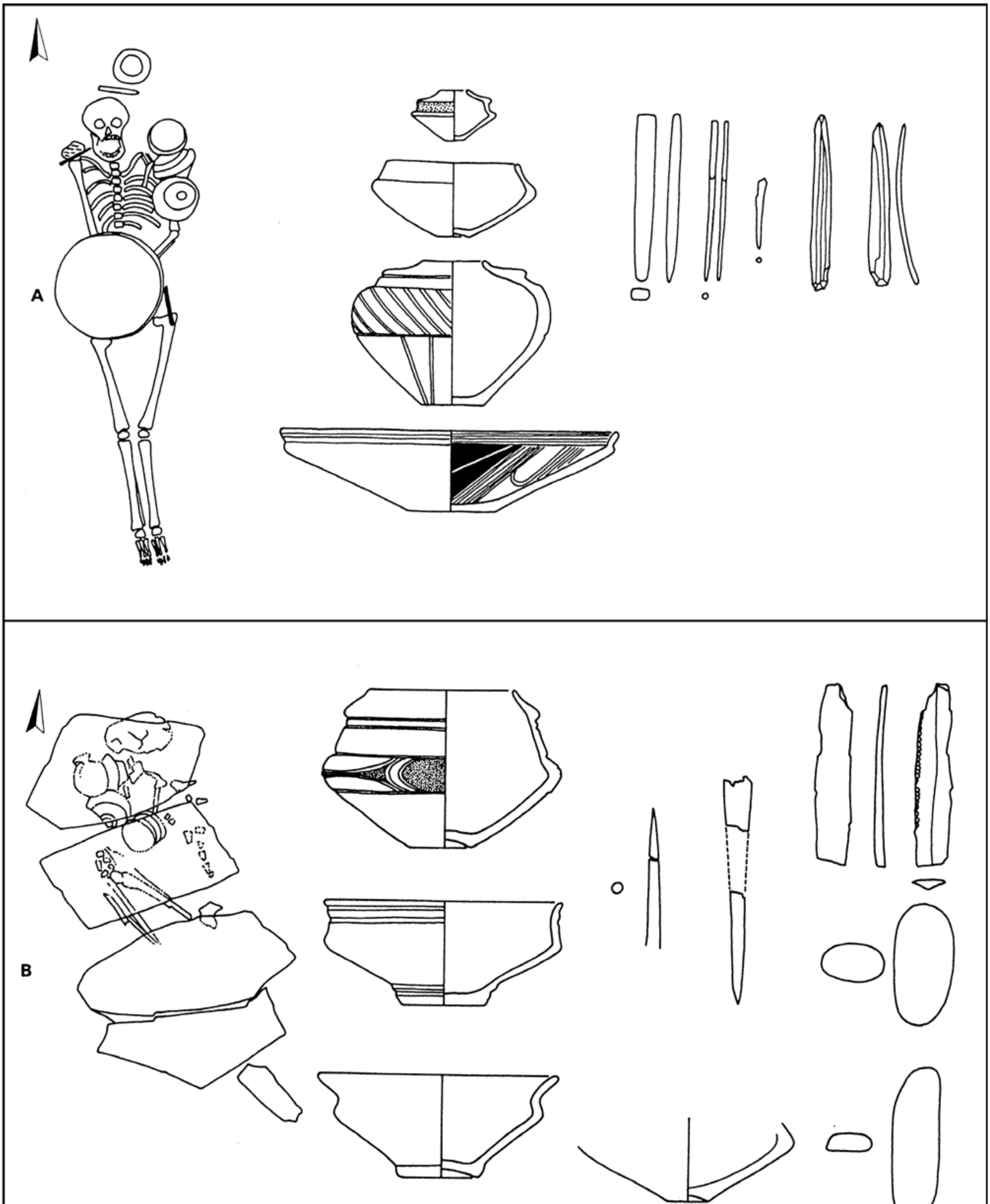


Fig. 5.14: Graves of the Varna culture/group from the cemeteries of Devnja (above) and Durankulak (below; after Lichter 2001, 92 fig. 36A, 104 fig. 47B).

Fig. 5.15: Distribution of the Copper Age Bodrogkeresztúr culture along Tisza and Danube (after Patay 1974, Beilage 1).

or the hierarchical basis of patronage (Chapman et al. 2006, 173–176). Should we not seek then to understand the early 'elite' burials and the rich cenotaphs as well in the context of a complex web of ritual practices, differently identified individuals and in terms of their burials' significance for a wider community?

5.3.2 'Tribal Cycling' During the Late Neolithic and Copper Age of the Carpathian Basin

We should not attempt to extrapolate from the Varna evidence to a coherent picture of social evolution, in fact socio-political hierarchisation is not at all a precondition of Eneolithic/Copper Age metallurgy. The latter point may be illustrated by a move into the Carpathian Basin, some centuries later than Varna and closer to the metal artefacts discussed above. Along the Tisza river the cultures of Tiszapolgár and Bodrogkeresztúr (fig. 5.15) represent the Hungarian Early and Middle Copper Age of the late 5th and early 4th millennium BC (Bognár-Kutzián 1972; Patay 1974; Patay 1984, 6). Both groups buried their dead in cemeteries outside the settlement, with inhumations stretched out on the back alongside crouched burials in Tiszapolgár and with crouched burials predominating in Bodrogkeresztúr (fig. 5.16; Bognár-Kutzián 1963; Patay 1978; Meisenheimer 1989; Lichter 2001). There is some variation in the choice of grave goods with time and according to region. Initially large sets of pottery may be found, in both cultures supplemented by axes of copper or stone, further weapons or tools as well as ornaments made of stone, silex, bone, shell, copper and occasionally gold (fig. 5.17; Lichter 2001, 280–289, 330–344).

A number of more or less well documented cemeteries of both groups are known. Burial customs and grave furnishings were recently analysed in detail by C. Lichter (2001). He concludes that in the Tiszapolgár culture among the (anthropologically) female burials there were two groups and among the male burials three groups identifiable through differences in the number and quality

Fig. 5.16: Graves of the Copper Age Tiszapolgár (below) and Bodrogkeresztúr (above) cultures (after Lichter 2001, 275 fig. 121, 319 fig. 139).

of grave goods. In particular it was the presence of an axe which distinguished a small number of men. Access to this group, however, solely depended upon (anthropologically determined) age with no indicators of hereditary status. Access to all other groups does not show any patterning; they seem to reflect aspects of the habitus, individual or group identity of Copper Age woman and man in broad terms. This scheme as well as the small number of individuals living and being buried at the same time indicate that the cemeteries belonged to settlement units of limited size, possibly organised along kinship lines. Male authority was derived from age and personal achievement but hardly extended beyond the immediate co-residential unit or the limits of the individual's lifespan (Lichter 2001,

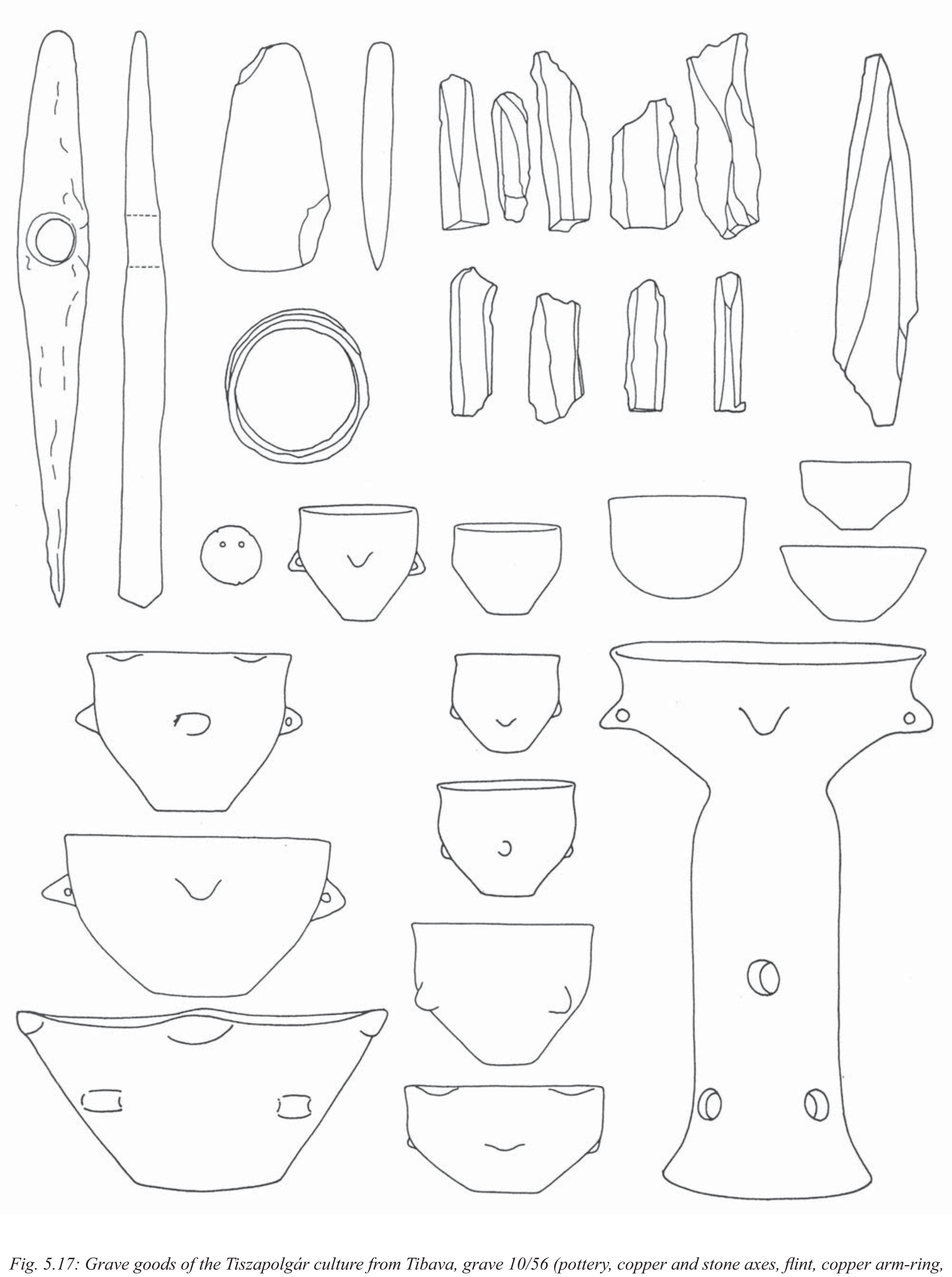


Fig. 5.17: Grave goods of the Tiszapolgár culture from Tibava, grave 10/56 (pottery, copper and stone axes, flint, copper arm-ring, gold pendant (after Lichter 2001, 285 fig. 127).

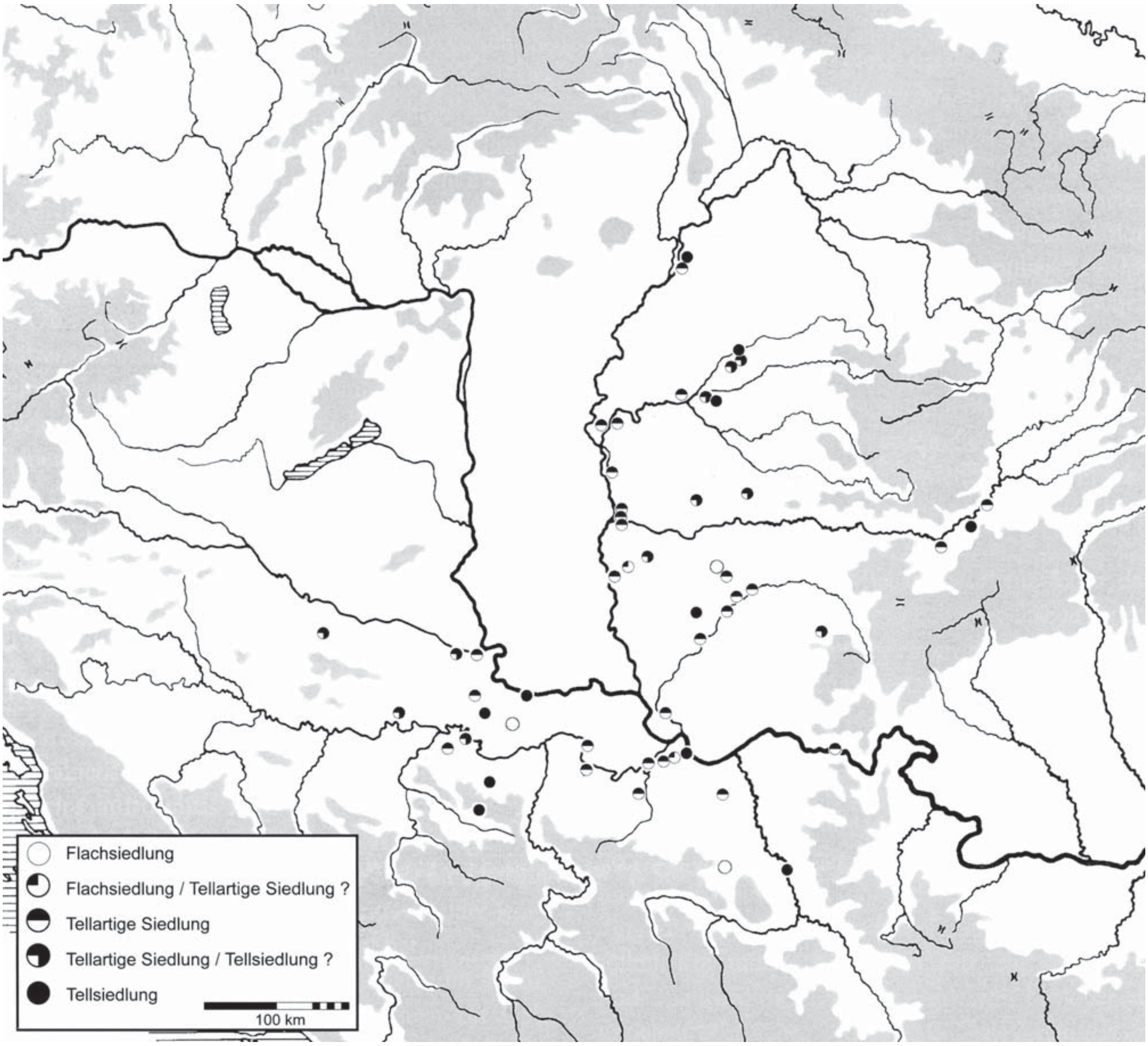


Fig. 5.18: Distribution of Late Neolithic tell sites and contemporaneous non-tell settlements in the Carpathian Basin (after Link 2006, 12 fig. 6).

289–291). In Bodrogkeresztúr the situation is much the same with three groups of male and female crouched burials respectively. Lichter (2001, 344–349) demonstrates that with male burials it was age, not hereditary status, which governed the choice of grave goods. With an estimated group size of 30 to 50 people, the authority of older men, Patay's (1974, 36–37; 1978, 56–58) 'Sippenhäuptlinge' (chiefs), was of limited range. Distinguished by age and possibly by individual merit their ability to assert oneself hardly affected more than the own kinship group.

The settlement evidence confirms this conclusion, as the 'Copper Age' of this part of south-eastern Europe is characterised by a dispersal of settlement structure and the abandonment of 'Late Neolithic' tell sites (fig. 5.18; for terminology and chronology see chapters 2.1 and 5.2). This process did not affect all Late Neolithic groups at precisely the same time (Gogâltan 2003; Link 2006; Parkinson 2006). Though there is regional variation, the outcome is much the same: firmly integrated communities with elaborate ritual, drawing their cultural identity from permanent focal (tell) sites in the landscape, were replaced by a loose network of rather impermanent settlement units and an emphasis on widespread (individualised) alliances and exchange systems (Tringham 1991, 273–281; Parkinson 2002b, 391–394; 2006, 39–63; Link 2006, 65–81). Many explanations have been proposed to account for this culture change with older work focusing on catastrophic climate events, migration or some ill-defined influences, especially from the northpontic region (e. g. Lichardus 1991c; Gimbutas 1994; Todorova 1995). Subsequent models came to a more differentiated view of environmental change and stressed adaptations in subsistence economy with subsequent effects on settlement and social structure (e. g. Chapman 1981; Parkinson 2002b). Explanations predominantly drawing on social aspects were proposed, with assumed structural limits to

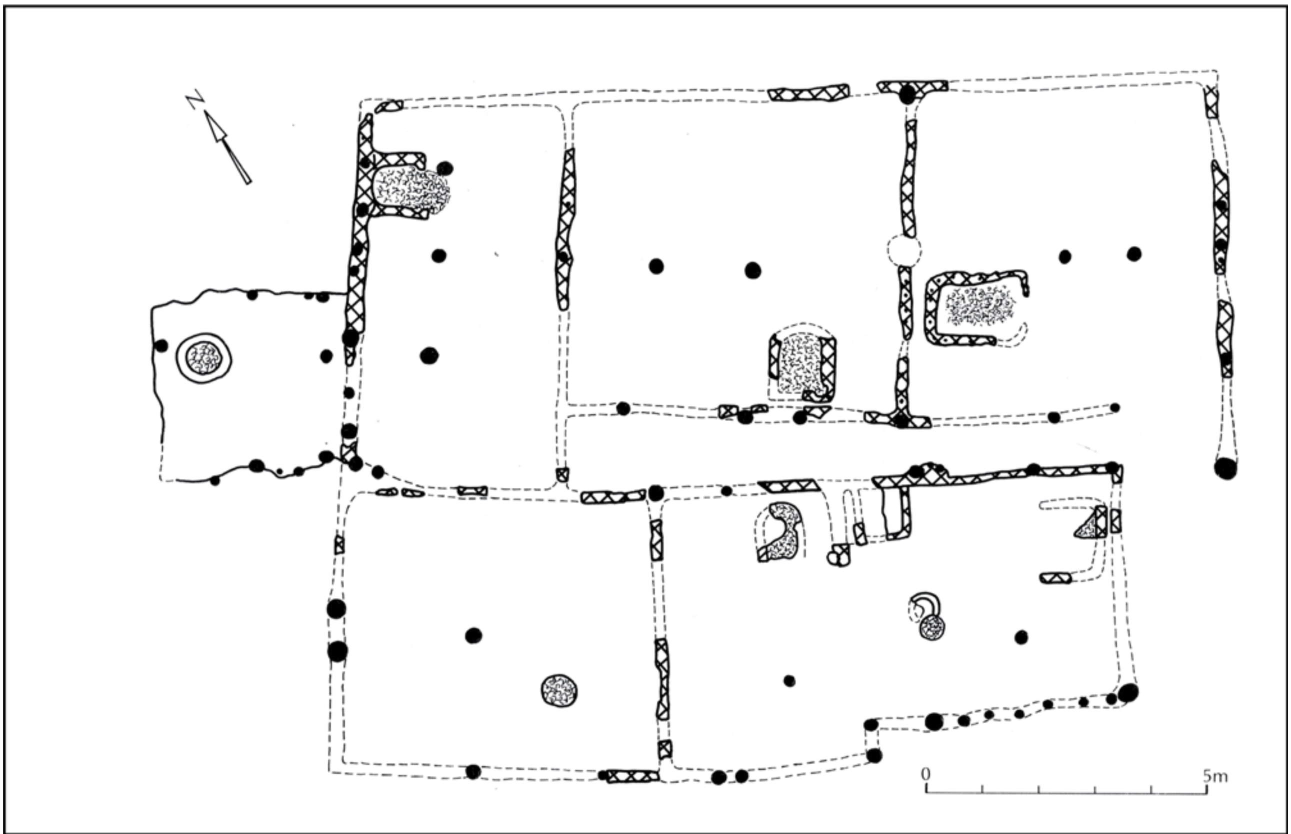
Late Neolithic community size, followed by dispersal and a reorganisation of autonomous households (e. g. Tringham 1991; 1992). Finally, an emphasis is also put on culture, continuity of place and time, community and tradition as expressed by tell settlement, which supposedly lost its meaning to Copper Age population (e. g. Whittle 1996, 78, 84–85, 112; Chapman 1997; Stevanović/Tringham 1997; Bailey 1997; 2000, 168–169).

Irrespective of why this change took place, in both the Late Neolithic and the Copper Age there are no signs of permanent hierarchies, control exercised over adjacent settlement units or distinctions in personal identity other than age and gender (Sherratt 1984, 131–132; Tringham 1991, 280; Whittle 1996, 72–76; Bailey 2000, 195–203; Parkinson 2002b, 391–394). We therefore witness *culture* change, not social evolution or its reverse. A model of 'tribal cycling' has been suggested to account for this phenomenon without reference to institutionalised ranking or social evolution (Parkinson 2002b; 2006). Now, the notion of tribal society goes back to 19th century cultural anthropology, and ethnographic reality is much more complex than social typologies have us believe (see chapter 5.2.3; Fowles 2002). As for chiefs or great men we must not use such concepts to account for the archaeological data in any straightforward way (Yoffee 1993; Roscoe 2000). However, what is convincing about W. Parkinson's work (2006) in the Hungarian Körös region is the level of scrutiny in his spatial analysis and the attempt to relate his findings to social structure as well as to human perception and agency. From the household level up to large clusters of settlements there are changes in the structural levels of settlement organisation. These are seen to reflect both changes in day-to-day practices and in the organisational principles underlying Late Neolithic and Copper Age society respectively.

With some regional variation in the Late Neolithic there are large, multi-room and possibly two-storey houses (e. g. Hódmezővásárhely-Gorzsa, Berettyóújfalu-Herpály and Uivar-Gomila; Meier-Arendt 1990; Lichter 1993; Gogâltan 2003; Schier/Draşovean 2004; Link 2006). Their internal division, for example the presence of more than one oven or fire-place (fig. 5.19), hints at the co-residence of several nuclear families and a high degree of interaction and cooperation at household level (Parkinson 2002b, 401–419; 2006, 123–156). In some cases such households are seen to group into distinct clusters within the wider settlement and these neighbourhoods are interpreted as the basic unit of Late Neolithic communities, the focus of daily life, production and social reproduction (see also Link 2006, 57–58). Above the individual settlement unit, on a regional level Parkinson is able to identify groups of settlements called clusters or superclusters generally organised around tell sites. These were focal points for exchange and may have expressed a sense of continuity. They were not, however, in social and functional terms very much distinct from surrounding settlement units. It was not power that held the system together in the sense of the control exercised by a central place over its tributaries (Link 2006, 59–63, 84). Rather the organising principle of clusters and superclusters was identity, reinforced by events such as regular gatherings and feasting (e. g. Polgár-Csőszhalom: Raczky et al. 2002; Gogâltan 2003, 242). Towards the outside, social boundaries were marked and maintained by material culture, for example by differences in pottery style (Parkinson 2002b, 419–424; 2006, 157–184).

Copper Age houses, on the other hand, are smaller and show a lack of comparable internal complexity (e. g. Kenderes-Kulis und Körösladány-Bikeri; somewhat later Tiszalúc-Sarkad: fig. 5.20; Patay 1995; 2005; Parkinson 2002b, 403–404; 2006, 102, 116–117; Parkinson et al. 2004, 67–68; Link 2006, 56, 59). There is no equivalent to the structural level of Late Neolithic neighbourhood, i. e. groups of houses (households) spatially combined to form a functional unit. Instead settlement consists of the smaller houses of one nuclear family each. Parkinson (2002b, 401–426; 2006, 123–184) suggests that activities previously located in the neighbourhood were now carried out communally on settlement level. Settlements were relocated more frequently and clusters or superclusters tend to become less visible in the archaeological record. In total there is a reduction in structural levels and complexity combined to increasing mobility of the settlement system as a whole (fig. 5.21). The earlier emphasis on group identity and integration is weakened and social boundaries towards neighbouring communities (clusters) lost their former importance. Since this process does not correspond to obvious changes in social structure, for example a decline of political authority exercised by a ruling elite at tell sites over surrounding settlements, Parkinson suggests modifications within the limits of structural flexibility of a tribal society. In what was fundamentally the same society and population, structural levels that had previously been actualised became latent. Traditional aspects of life and social organisation reproduced by the day-to-day practice of numerous individuals began to fade when other options were acted out, latent ways to live were realised and began to shape perception (Parkinson 2002b, 398).

During the Eneolithic/Copper Age of south-eastern Europe there were groups widely different in terms of their settlement (e. g. tell vs. non-tell), economy and most likely the mechanisms of their social organisation/integration as well. It is important that this should not be read as advocating the existence of marked and stable political hierarchies anywhere in the area in question; quite the opposite in fact (see the above discussion). Few of them, and the groups of the Carpathian Basin in particular, provide evidence of a strong societal impact of metallurgy. The opposite is also important to remember, that no specific, that is typically 'hierarchical' system, was required to support a 'Copper Age' metallurgy and make its products desirable for the communities involved. Elaborate and massive copper shaft-hole implements occur in both tell-building communities such as in the Vinča culture site of Pločnik as well as in quite unspectacular dispersed systems such Tiszapolgár and Bodrogkeresztúr. Clearly, we should beware of reductive approaches to the *one* 'Copper



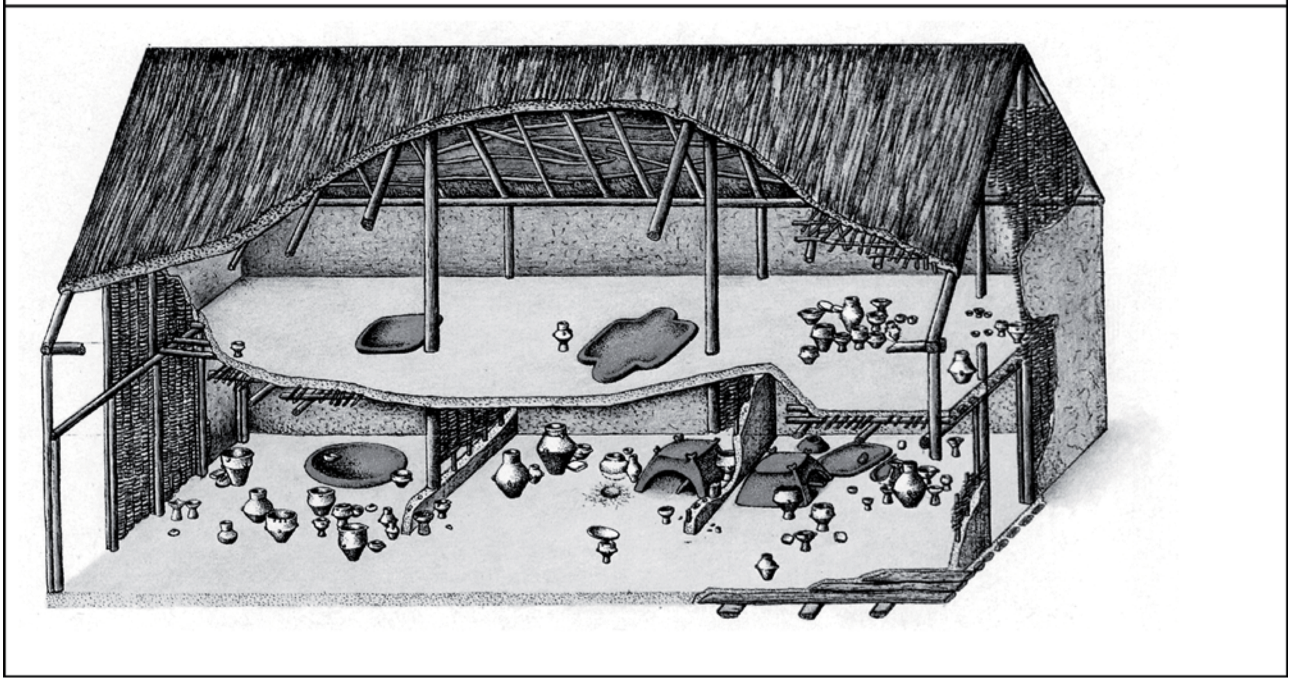


Fig. 5.19: Plan of a Late Neolithic house at Hódmezővásárhely-Gorzsa (above; Tisza culture); reconstruction of a large two-storey house of the Late Neolithic at Berettyóújfalu-Herpály (below; Herpály culture; after Meier-Arendt 1990, 39 fig. 22, 122 fig. 171).

Age' throughout south-eastern Europe and any links drawn between the practice of metalworking and any specific kind of Copper Age society.

5.4 Kinship and the Spread of Metallurgical Knowledge

The social and material world is built up from day-to-day practices. The perception of ourselves and our role in society is shaped by daily experience, and this is also how inequality and power are transmitted and reproduced. However, there is also an enabling side to practice, and the social domain is not static or given but consists of individuals and groups drawing on rules and manipulating them in pursuit of their aims (Bourdieu 1976, 139–227; Giddens 1979, 49–95; 1984, 1–37; Ortner 1984, 149–157;

Fig. 5.20: Settlement plan and houses of the Copper Age Hunyadi-halom culture at Tiszalúc-Sarkad (after Patay 2005, Beilage 3).

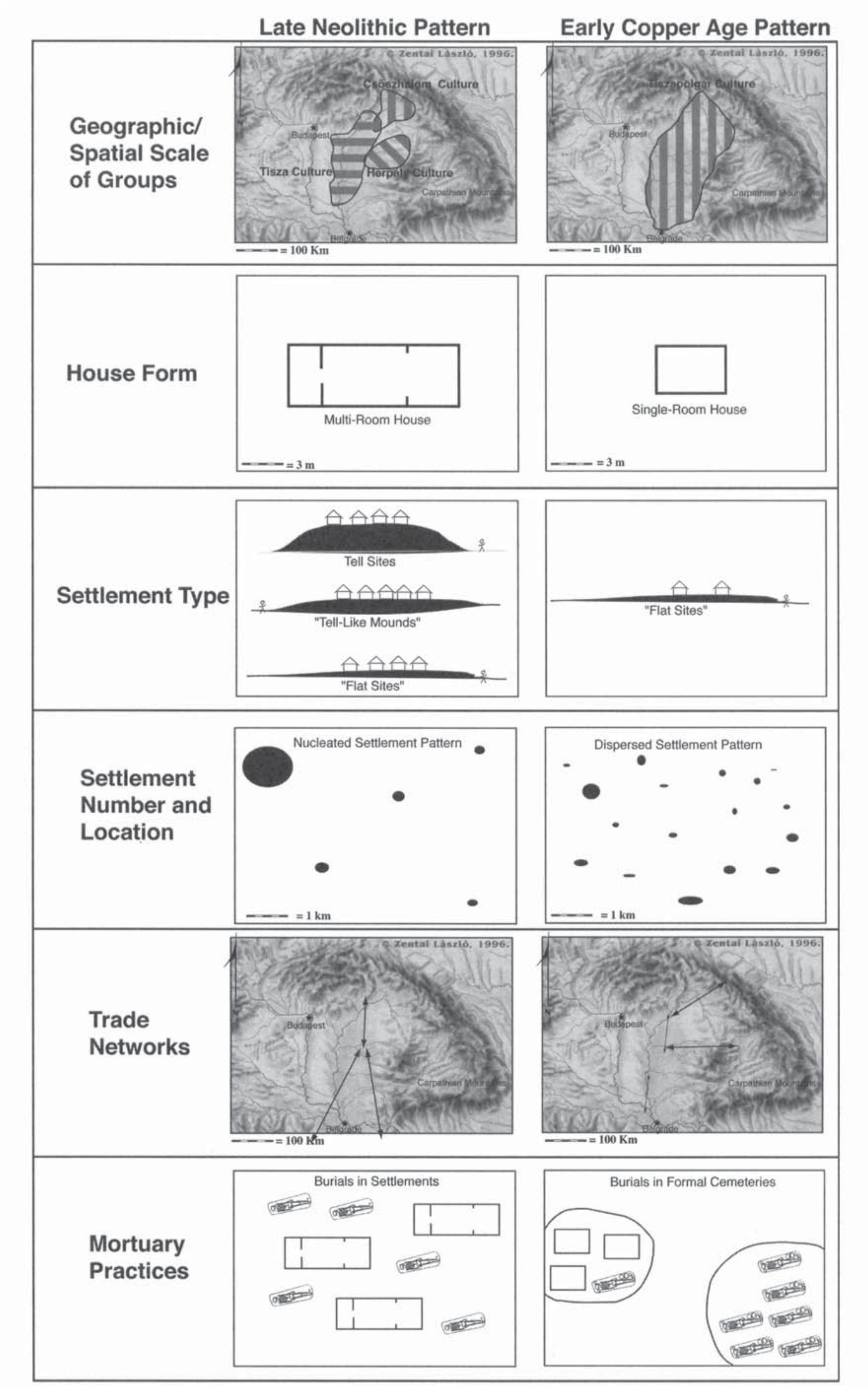


Fig. 5.21: Changes in settlement pattern from the Late Neolithic to the Early Copper Age of the Carpathian Basin (after Parkinson 2002b, 392 fig. 1).

Shanks/Tilley 1987, 61–78; 1992, 116–134; Miller 1995, 64–65; Dobres/Robb 2000; 2005). We must be wary of projecting back the – supposed – efficiency of medieval or modern rule and elite discourse on prehistoric societies. Instead, it is likely that in a majority of Neolithic to Iron Age groups authority referred to kinship groups in the first instance, and the ability to exercise power beyond these collectives was restricted both in a temporal and spatial sense (see above). There was not the one 'chief' in charge, but authority was exercised on different levels and by different (groups of) people from the household, via (sub-) clans, lineages and on to larger entities such as the 'tribe'. We should be looking in the archaeological record for small-scale patterning and evidence of mechanisms other than just power and politics to regulate and express social relations. Erroneously, this is often misunderstood as a claim that the prehistoric groups in question were egalitarian and in some way 'primitive'. We need to be very clear, therefore, that hierarchy is not the same as complexity, and even if we find a lack of institutionalised ranking a group might still be complex (Rowlands 1995; Wynne-Jones/Kohring 2007; Souvatzi 2007): rich in individual identities, in the manifold ways people interact, in the way kinship is expressed and integration takes place by material production or by reference to common ancestors and is lived out in ritual and feasting. Ownership, material production or decision-making may be communal and still allow the mobilisation of people against a common enemy and direct considerable workforce towards an effort that is agreed upon.

Why then, apart from the evolutionist notions mentioned earlier, does the search for political hierarchies appear so well justified, and – turning back to metallurgy – why do human labour and material production so readily become enmeshed in narratives of managerial elites and control over production and exchange? Possibly, an answer should refer to the sheer impressiveness of the archaeological record. Almost throughout prehistory we are confronted with examples of highly elaborate material culture, be it artefacts, graves or architecture, which we cannot imagine 'ordinary' people were capable of crafting or why anyone should have bothered without aggrandisement in mind or pressure put upon him. Metallurgy, clearly, fits in here and the widely held obsession with its control by higher ranking individuals. But there are numerous examples from the study of other prehistoric periods as well; right at the start of the Neolithic in Göbekli Tepe, Turkey (Schmidt 2006), there is monumentality on a massive scale, and naturally an 'unegalitarian and stratified social structure' and 'specialised craft' have been suggested (Özdoğan 1999, 227–231; see however Schmidt 2006, 246–248; see also R. Chapman 2007, 15–16). Similarly, all later evidence of communal labour directed, for example towards Megalithic monuments or fortified settlements is taken to imply and require elite control.

The ethnographic evidence of craft specialisation was reviewed many years ago by M. Rowlands (1971; see also Schlesier 1981; Costin 1991; Bisson et al. 2000; Neipert 2006; Kuijpers 2008), and clearly metallurgy cannot be said in any way to be tied up to elites, and part-time metalworkers may be able to produce the most complex objects. Accordingly, it will be argued below that the spread of Copper Age metallurgy may have taken place along kinship lines, and the communication of metallurgical knowledge did not require the presence of strong leadership and political control to be efficient. Similarly, political elites and attached specialised miners are not a pre-condition for impressive mining works. Rather, there is ample evidence for the ability of small-scale tribal societies to operate such activities on a consensual basis without coercive force applied. Furthermore, mining is rarely done continuously throughout the whole year but typically is a seasonal activity carried out by a group of participants which may fluctuate from occasion to occasion and from year to year (see chapter 8; Kienlin/Stöllner 2009).

But let us turn aside for some more general comments first, because discussions on craft specialisation and labour surely reflect modern western notions of work and its incentives as much as they tell us about prehistoric conditions. We tend to mistake the nature of labour, production and exchange in traditional society (Miller 1995, 69–71; Ortiz 2002, 893–898). Our notion of productive work as opposed to leisure time is a firmly modern concept that fails to acknowledge the social embededness of such activities as agriculture, the production of material items or co-operative efforts in raising a fortification or sanctuary. Participation in communal activities or support provided to neighbours or kinsmen may be a social obligation. It can serve as much to establish or reaffirm social ties as to produce a specific number of artefacts, a certain amount of food or raise a defined number of megaliths. Leaders such as Big men may not be so much an elite commanding the labour of followers for their own projects and benefit. Rather, these projects raise the prestige of both Big men and their followers, so everyone has an interest in cooperating on them (P. Roscoe, personal comm.). To benefit disproportionally on such occasions, avoid them or keep a precise account of time spent may be seen to deny this social meaning of labour. Similarly, upon exchange an imbalance in terms of effort and time involved in the production of an object may not be perceived as an offence. As M. Sahlins (1974, 278) observed, there may be an 'indeterminancy of the rates', which allows for an assessment of value and labour in terms of mutual benefit (see also Gregory 2002, 929–931).

The division of labour along gender lines as well may carry cultural implications instead of following technological or functional considerations; and any such differential allocation of responsibilities does not constitute what we tend to perceive as craft specialisation (Ortiz 2002, 899–905). Being firmly social labour in such a context clearly offers the potential to establish inequality in terms of wealth, knowledge and eventually power or status as well (Ortiz 2002, 902–903). But this is only one side of the coin and we should not overemphasize the asymmetry and dynamics of such systems of labour, knowledge and exchange. This is particularly so when operating with concepts that were originally conceived in an evolutionary

framework such as Durkheim's mechanical and organic solidarity (Ortiz 2002, 903–904). It would seem that any kind of cooperative behaviour, communal decision-taking and self-regulation is vastly underestimated in our notions of prehistoric society. Hence our difficulties to think about Göbekli Tepe in terms of small groups of hunter-gatherers cooperating on a seasonal basis with neither ranking involved in labour mobilisation nor unequal access to production or consumption. Hence our conviction that metal triggered social hierarchisation, and copper invited attempts by higher ranking individuals to increase efficiency and stability of their power, despite ethnographic evidence pointing to the possibility of an essentially kinship-based mode of organisation and transmission of metallurgical knowledge.

Turning back to metalworking there is one aspect of the metallographic data that is remarkable. Our Eneolithic/Copper Age (metallurgical) horizons 1 and 2 cover a substantial period of time, and the axes in question are known from a large area of the Carpathian Basin and beyond. Still we find a high degree of standardisation in the basic approach (e. g. the application of heat either by hot working or annealing as opposed to cold worked as-cast microstructures which are missing), and even the variation discussed above seems to relate to larger entities (i. e. shaft-hole implements as opposed to flat axes of horizon 1, both taken together as opposed to horizon 2 flat axes; see chapters 3 and 4). We are not talking about the very first evidence of metallurgy in south-eastern Europe, but still we may ask how such uniformity initially developed and was maintained in the face of technological change (horizon 1 to 2). Apart from the changes in settlement pattern and a reduction in structural complexity (see chapter 5.3.2; Parkinson 2002b; 2006) it is likely that much of a Neolithic lifestyle persisted into the Eneolithic/Copper Age. In both periods we are dealing with a population mainly depending on agriculture and animal husbandry. In both there is evidence of the production of elaborated objects not directly related to subsistence or daily life and requiring a certain amount of specialist skills. Exchange of raw materials from far abroad is another common feature, although in the Neolithic these might have reached wider distribution in contemporary society (e. g. imported silex varieties) and the Eneolithic/Copper Age possibly saw attempts at restricting access to new kinds of prestige goods. Finally, if we accept that hierarchies and institutionalised social ranking were largely absent both in the Neolithic and in the Eneolithic/Copper Age, how did innovations spread in Eneolithic society? How was renewed uniformity established without elite control over attached fulltime craft specialists, their movement and knowledge? Through what mechanisms, other than elite exchange and communication, did the knowledge of metallurgy (as well as of subsequent innovations in casting and forging) find broader acceptance? How was metalworking practice organised if not by elite control of raw materials, metalworking and exchange?

It is suggested that for an answer we have to turn to the essentially kinship-based organisation of traditional society (see chapter 5.2.3). This model has been recently explored for groups as diverse as the Early Neolithic LBK culture, whose rapid spread throughout large parts of central Europe has been explained by expanding lineages or clans (e. g. Lüning 2005; Frirdich 2005), to Early Bronze Age cemeteries (see chapter 8.4). Apart from structuring traditional groups as a whole, kinship is of particular importance for any kind of specialised tasks extending beyond everyday household-based production (Harris 1989, 151–200; Helbling 2003). This is because the right and the ability to carry out such activities often depends on affiliation to a particular segment of society. One does not become a founder or smith in the same way we decide to study archaeology, but by descent from a particular lineage. The individual is not only taught the knowledge and practical skills required for his future 'profession' but picks up the norms and values of his descent group. By socialisation he or she becomes not only a metalworker but finds their position in a particular kinship group and in society as a whole (Rowlands 1971; Schlesier 1981; Costin 1991; 2000; Ottaway 1994, 221–222; Gosselain 2000; De Barros 2000; Neipert 2006, 51–75, 107–114; Kienlin 2007; Kuijpers 2008, 51–67).

Accordingly, for example, it has been demonstrated that people with a different regional origin and/or cultural background occupied the small hamlets and cemeteries of the Early Neolithic LBK culture. This is framed in terms of their ancestors already adhering to a Neolithic lifestyle or only more recently having abandoned Mesolithic traditions. Members of different lineages or clans were present in the same settlement, and their different origins also affected the spatial arrangement of their houses over several generations (fig. 5.22; e. g. Lüning 2005). In line with general expectations of such kinship-based systems, this also affected their access to exchange networks. The inhabitants of adjacent houses demonstrably obtained their different varieties of flint from a number of different often widely distant sources (e. g. Frirdich 1994; 2003; 2005; Gronenborn 1999; 2003; Petrasch 2002; Lüning 2005; 2006). Similarly, in Late Neolithic wetland sites there is evidence of a differentiated patterning of economic practices on the household level, which points towards different traditions and kinship affiliations of the inhabitants (fig. 5.23; e. g. Schlichtherle 2004; 2009).

In such kinship-based groups there is great variability with regard to craft specialisation, organisation of production, social position of (metal-) craftsmen, the activities carried out and objects produced. We find specialised fulltime metalworkers attached to an elite alongside those producing for a village community who derive most of their living from agriculture; metalworkers firmly integrated into local groups alongside those who display ethnic differences and high mobility; smiths held in high esteem and those subject to superstition and segregation. Yet there are common features within this diversity that help us understand the Eneolithic/Copper Age situation under discussion. In oral societies transmission of practical skills involves the elders demonstrating the adequate way to do things and imitation

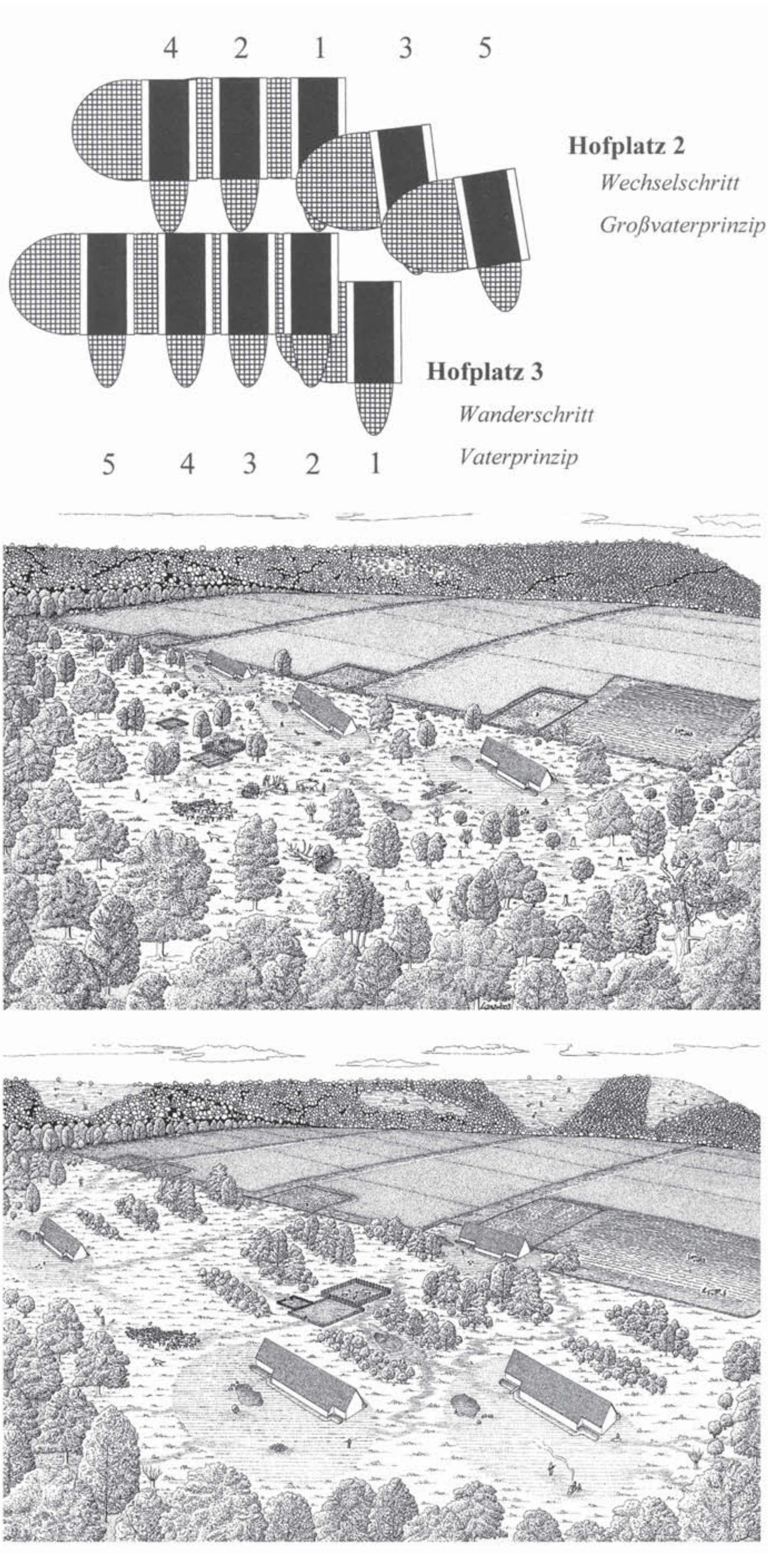


Fig. 5.22: The Early Neolithic site of Schwanfeld, Germany – suggested rearrangement of houses during several building phases following different genealogical principles (above; middle and below: reconstruction of the Schwanfeld hamlet during its earliest and latest phases; after Lüning 2005, 50 fig. 2, 59 fig. 10, 62 fig. 12).

Fig. 5.23: The Late Neolithic site of Bad-Buchau Torwiesen II, Germany – differentiated patterning of animal bone assemblages and economic practices on the household level (after Schlichtherle 2004, 16 fig. 4).

by the young ones (Pfaffenberger 1992; Rowlands 1993; Goody 2001; Ottaway 2001). This largely non-verbal and non-theoretical learning is accompanied by narratives providing a 'mythological' background to the craft itself, the group's ancestry and life in general. In the first instance this process involves communication between different generations of one family actually sharing the same house or living close by. Characteristically, however, in kinship-based societies there are wider networks linking individuals on the basis of common descent without being members of the same household. Such kinship ties are reinforced, for example, by ritualised feasting. Even without such occasional gatherings, however, and across larger distances they constitute a sense of identity and encourage communication. A common ancestry, be it biologically or culturally constructed, thus provides rules for interaction and may enable individuals not initially personally acquainted to interact on a familiar basis.

The communication of metallurgical knowledge did not require the presence of strong leadership and political control to be efficient. More likely it was kind of 'self-organising' among segments of Eneolithic/Copper Age society familiar with the practice of metallurgy. Of course we do not know what their precise activities and status were, nor if they were the same in the whole of south-eastern and central Europe. Yet it is likely that their command of metallurgical (and probably ritual) knowledge set them to some degree apart from their non-metalworking neighbours and encouraged the formation of far-reaching kinship ties. Along these lines metallurgical knowledge was passed 'from hand to hand' by individuals who did not necessarily know anybody hundreds of kilometers away, but had grown up into similar traditions and shared a common identity. A system of communication came into existence that allowed the gradual spread of new casting techniques and approaches to forging such as the ones noted in our horizon 2 axes. The long radiocarbon chronology of Eneolithic/Copper Age south-eastern Europe tends to confirm this model of a decentralised spread of metallurgical knowledge both for the initial stages of (Late Neolithic) metallurgy and for subsequent innovations modifying traditional practice.

This processes are best understood as technological choices taken through time by countless individuals that were not determined in their action by any 'political' authority, but firmly integrated in kinship-based networks of information exchange and decision-taking.

In a number of recent papers, it is argued by B. Roberts and his collaborators (Roberts 2008, 364–365; Roberts 2009b, 135–136; Roberts/Thornton/Pigott 2009, 1018–1019) that we should not overemphasize the primacy of the metalworking sector in the spread of metallurgy. They draw attention to the demands of the metal consumers and the local communities supporting copper production and working (see also Lemonnier 1986; 1992; Pfaffenberger 1992). This is an important point because copper objects somehow had to be accepted or incorporated into daily life and communal practice – be it for adornment, symbolic purposes or somewhat later for functional ones. Also some metallurgy-related activities may have required the commitment of a broader segment of society in terms of manpower or their readiness to provide food and other resources that may have been necessary such as wood/charcoal, clay for refractory ceramics or tools in the widest sense. On the other hand, this approach should not be contrasted with the notion of a kinship-based practice of metallurgy advocated above. Lest there are misunderstandings one possible point of disagreement should be discussed, namely the relative distance of metalworkers to 'their' supporting communities.

In the above model it is suggested that metallurgical knowledge was passed along kinship lines, and command of such (ritually framed) knowledge set apart those involved from their neighbours and community. This is true to the extent that – ethnographically – in oral societies some kind of 'secrecy' seems to be a precondition for the transmission and stability of such 'special' knowledge and related practical skills. It should not be taken to imply, however, that metallurgists were foreigners to their supporting communities, as there is a tendency to do so in the studies of B. Roberts (2008, 364 ; 2009b, 135–136; Roberts/Thornton/Pigott 2009, 1018–1020). This concept is used to account for the spread of metallurgy over large distances and to counter claims for an autochthonous development both in western and south-eastern Europe (Roberts 2009a, 472–473; Roberts/Thornton/Pigott 2009). However, ethnography implies that (itinerant) metalworkers operating in a foreign cultural context are rare. Typically mobility if any is restricted to an area with some kind of previously established contact and affinity in terms of communication, exchange and/or a broadly similar socio-cultural background (Rowlands 1971; Neipert 2006). Hence in the present model the emphasis is put on a gradual dissemination of metallurgy and metallurgical knowledge, not a series of leap-frog jumps spread over large distances. The latter may occur with early import finds, but we must be aware that different burial or hoarding customs may confuse our picture of the original distribution of metal in prehistory. It is suggested that cases of a discontinuous appearance of proper metallurgy are down to bad archaeological visibility or the current state of research.

In the present model metalworkers are conceived of as more or less firmly integrated in local communities, and it is suggested that most metallurgical activities and needs could be accommodated within the community structure (see also Kuijpers 2008, 30–31, 36–38 on the problem of 'detribalisation' involved in the notion of itinerant metalworkers). Demand initially was low, the amount of copper won and worked was small, and metal only gradually replaced other materials such as flint or stone in the large-scale production of weapons and implements. This implies some kind of part-time specialisation and parallel involvement of metalworkers in subsistence activities. Thus, metalworkers were not that much 'special' or foreign, and pressure put on local communities to support metallurgy would have been low. In addition we need to differentiate the various activities involved. If copper was obtained from abroad there may have been pressure on the resources required of those individuals or groups that participated in exchange and were in want or need of copper objects (either directly or via 'their' metallurgist). But it certainly did not require substantial community involvement. Otherwise mining and smelting were carried out by the community itself. This may have involved seasonal mobility and the workforce of a larger number of individuals, for in fact such activities are unlikely to be operated by a single family etc. alone. So here is an element of community involvement with a larger number of individuals potentially involved or required. However again, these are low-intensity activities that may be carried out on a seasonal basis and scheduling conflicts with agriculture can easily be avoided (mind also the earlier mining for stone and flint; e. g. Körlin/Weisgerber 2006). It is another matter whether mining and/or smelting were communal events or involved 'secret' knowledge, and attempts were made to restrict access to such activities. The latter has been suggested, for example, for stone and copper mining on the British Isles and smelting in the Bronze Age Aegean (e. g. Edmonds 1995, 49–66; O'Brien 2007, 21–27; Doonan/Day/Dimopoulou-Rethemiotaki 2007, 114–117; Catapotis 2007, 214–219). In any case, people may not have been working *for* their metallurgist or have been obliged to keep the provision of a valued commodity going; but they may have been engaging *with* him (her?) in some communally sanctioned raw material procurement activity among others.

Even more so the casting and working of copper should be seen in the context of already existing 'technologies' and intra-community 'specialisation': It is thought likely that the knowledge and skills involved were 'special' or complex enough to be handed down in particular families or lineages or clans only (see above). So not every community member was able to cast and work copper. It is possible that metalworkers' knowledge of and ties with segments of far-off communities were closer than normally was the case, particularly so if they had to procure copper from abroad themselves. But to a certain extent this may reflect the situation of working other materials such as stone,

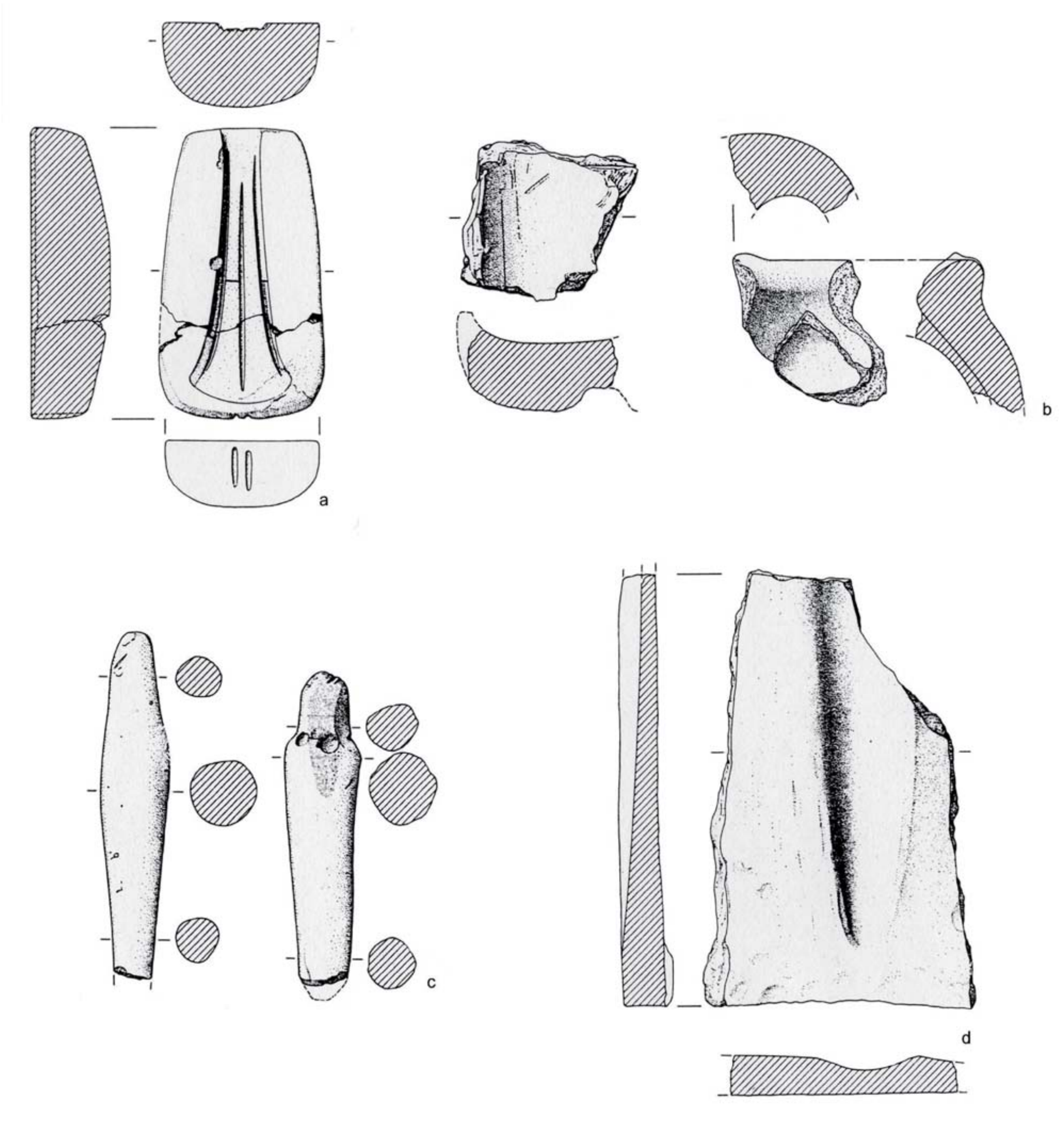


Fig. 5.24: Feudvar, Serbia – remains of metalworking activities from the Early Bronze Age workshop (a. mould, b. broken up moulds for cire perdue casting, c. cores, d. grindstone; after Hänsel/Medović 2004, 104 fig. 7.1, 106 fig. 9.17/18, 107 fig. 10.1, 108 fig. 11.9/10).

flint, wood or bone, some of which were also obtained from abroad and provide early indications of intra-community 'specialisation'. In LBK times, for example, most people were able to produce the rather simple flint artefacts required. But not everyone did so with the same competence, and in some households there is evidence of a tradition of doing so preferentially and relying on other group members/households for other products or resources instead (see above). So initially metalworking may have been just one 'specialisation' or rather a preference among others, albeit one that developed into firm traditions and had a long-term tendency towards an increase in scale and a more full-time occupation. However, this should not be taken to imply that at an early stage there was high degree of mobility, and metalworkers were somehow detached from their communities.

To conclude this section, a good example for the integration of metalworkers in their communities postulated above comes from Feudvar in the Serbian Vojvodina and dates as late as the local Early Bronze Age (Hänsel/Medović 2004; see also Hänsel/Medović 1991; 1992; 1998; cf. Kienlin 2007). This is one of the very few European Eneolithic/Copper Age or Bronze Age workshops analysed *in situ* (cf. Bartík 1999), providing evidence for a wide variety of metalworking activities such as crucibles, moulds and cores, slag and grindstones (fig. 5.24). Casting was done in closed two-piece moulds and using the *cire perdue*

Fig. 5.25: Feudvar, Serbia – plan of the Early Bronze Age workshop in trench E (after Hänsel/Medović 2004, 89 fig. 2).

technique. The objects cast and worked include both ornaments such as pins and weapons or implements such as daggers, flanged axes, socketed axes, knifes and sickles (Hänsel/Medović 2004, 90–94, 96–98). Due to its size of about 9.5 m x 5 m, its orientation and its wattle and daub construction the workshop building fits into the regular layout and uniformity of the surrounding houses (fig. 5.25). There was no fireplace for cooking or structures for storage, however, nor any evidence of typical household production such as weaving. Instead, a part of the eastern wall is missing, and in this open anteroom there was a hearth for metallurgical activities with signs of intense heat and copper droplets providing evidence of casting. Unlike the surrounding houses there was a small court area to the south of the workshop building that was apparently used for working and finishing the copper objects, and also for the disposal of waste such as the broken up moulds from *cire perdue* casting (Hänsel/Medović 2004, 88–90). Since this workshop was clearly well organised, and there was considerable skill involved in the production of some of the objects, the excavators of this site suggest full-time craft specialisation (Hänsel/Medović 2004, 94–95). Because there is no evidence of cooking and storage it is thought that their customers supplied the metalworker(s) with food. There was no stock of copper either, and it is assumed that the raw materials were provided by, presumably well-off, customers and the production of prestigious copper objects closely followed their specifications. Summing up, Feudvar is seen as a proto-urban settlement and central place for its surroundings with evidence of craft specialisation, social differentiation and some kind of elites in charge of the smooth operation of the community and the whole settlement system (Hänsel/Medović 2004, 86–87).

We will never know if there was a full-time specialist at Feudvar as suggested by B. Hänsel and P. Medović (2004), but ethnography certainly implies that the range and the 'complexity' of the objects produced is not a good guide in this question (see above). Furthermore, there is other evidence to suggest an alternative reading of metalworking at Feudvar. The most obvious point relates to the situation of the workshop and its integration in contemporaneous settlement activities (fig. 5.26). There is no indication that the workshop was attached to some kind of elite neighbourhood nor is there evidence of the existence of marked hierarchies or political control at all. The interpretation of Bronze Age society is no less controversial than that of Copper Age social structure (see chapters 5.2, 5.3 and 8). But the emphasis typically put on minor variations in grave goods, order in settlement layout or workforce directed towards fortification systems, which are seen as evidence of socio-political hierarchisation, neglects alternative options of authority located on different levels of various groups of people, as well as the possibility of decentralised communal decision-taking. Hence, one does not have to agree with the traditional Bronze Age narrative of social differentiation, political hierarchies and craft specialisation.

Some of the problems involved may be highlighted by a short move from the Carpathian Basin towards the south, where most of these ideas in fact originate (e. g. Kristiansen/Larsson 2005). In Mycenaean times in particular, there is clear evidence of social differentiation, political rule, administration, redistribution and control exercised by the palatial centres over both subsistence economy and craft production. There are discussions whether and to what extent there was an 'informal' sector of economy below or alongside palace control (e. g. Dickinson 1994, 77–88, 95–97, 153–164; Shelmerdine/Bennet 2008, 291–292, 295–298, 303–308; Siennicka in print). After all, even

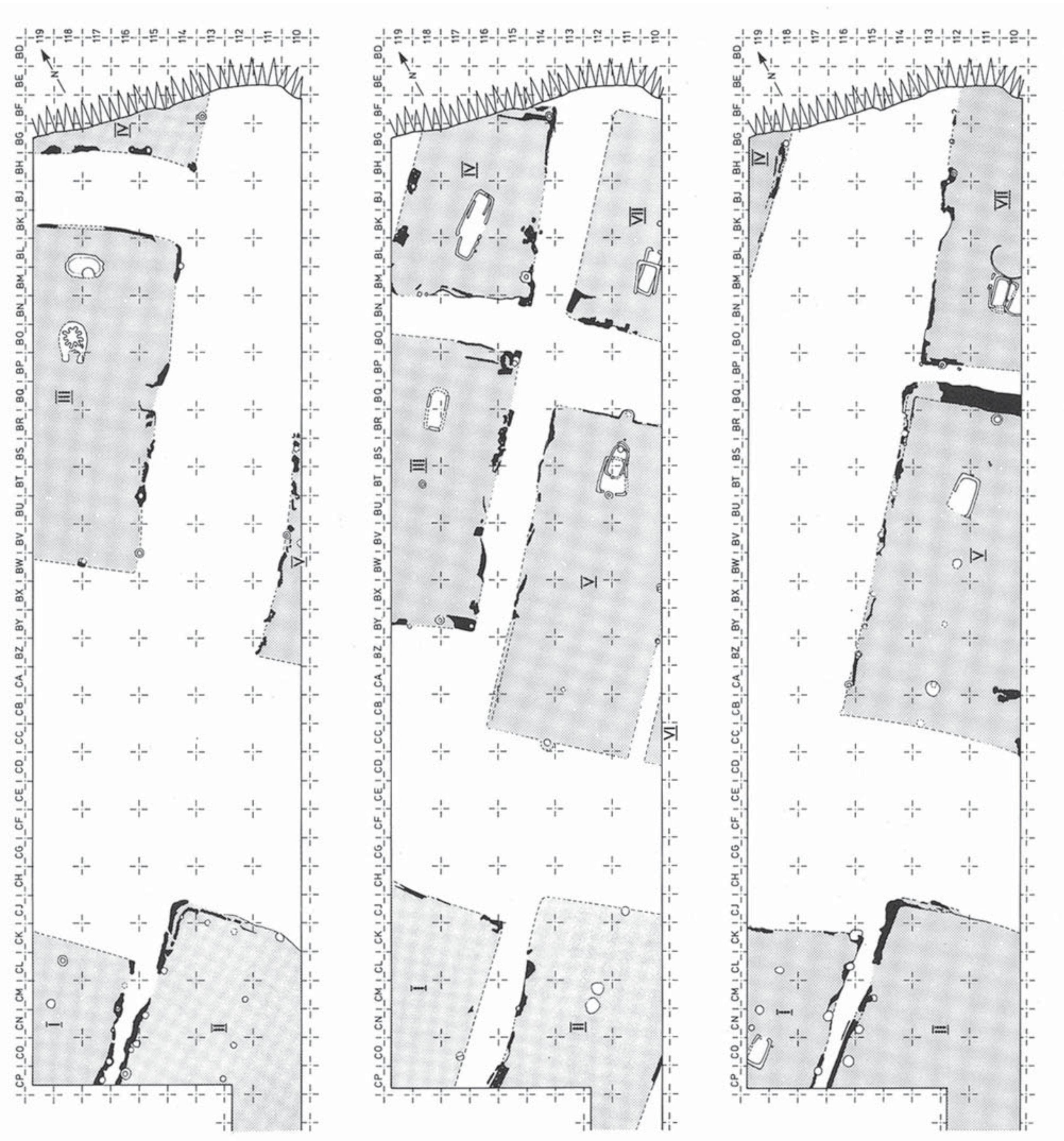


Fig. 5.26: Feudvar, Serbia – Bronze Age building phases in trench W (after Hänsel/Medović 1991, 69 fig. 7).

Mycenaean palatial rule might not have been as effective as supposed. However, in some places there certainly were administered workshops attached to the palaces and operated by fulltime craft specialists who were supplied with food rations and raw materials and operated only for elite/palace consumption. We are informed on the operation of this system by written records and administrative texts. However, this pattern is also clearly expressed by material culture, through the evidence of writing, seals and storage, as well as by architecture and settlement layout. The palaces have surrounding towns opposite rural settlements, palatial buildings and courts associated with political and possibly religious leadership (Maran 2006), there were communal banquets, storage facilities, administration and attached specialist production units for exotic materials, luxury items or weapons. None of this is matched by the Bronze Age tell sites of the Carpathian Basin, nor by sites along the other controversial 'route' along which an eastern Mediterranean style pattern of differentiated society and settlement is thought to have spread to central Europe via the Adriatic Sea, Istria (with the site of Monkodonja) and the Alps (Teržan/Mihovilić/Hänsel 1998; 1999; Hänsel 1996; 2002; Krause 2005a; 2006/07; see also chapter 8).

Accordingly, the Feudvar workshop was not attached to any socio-political centre (see above), and by its size it is unlikely that a larger number of persons were working there at the same time. This does not preclude substantial output if casting and metalworking took place all the year round. But its operators may as well be envisioned as the members of a family or kinship group that contributed to metalworking activities according to age and gender. It was their experience, training, apprenticeship or initiation that decided their role when they were not otherwise engaged in agriculture on a seasonal basis. Additional food may also have been supplied in exchange for their 'service' in metalworking, but it is unlikely that the workshop's 'inhabitants' utterly refrained from food preparation (cf. Hänsel/Medović 2004, 88, 94–95). Since the workshop building is devoid of any traces of 'regular' daily life such as cooking, one should take into consideration the possibility that its operators (maybe the metalworker and his family) actually lived in one of the surrounding houses. In any case, there was little distance between them or their workshop and their neighbours, and the entire spatial layout suggests integration within existing notions of the Feudvar village community.

The workshop and the surrounding houses were eventually destroyed by fire, and there is no evidence that metalworking continued on precisely this parcel of land (Hänsel/Medović 2004, 90–91, 95). So here might be an argument in favour of an itinerant craftsman, but note that only a part of the site has actually been excavated, and a rearrangement of households and activity patterns cannot be ruled out. If this was an itinerant founder and smith resident in Feudvar for only a limited period of time, one wonders how they could lay claim to a special workshop building. Why do their installations fit so neatly into local schemes of order and architecture instead of operating their craft somewhere in the vicinity? After all, it is likely that there was a local (family or kinship group) tradition of metalworking, that is only visible archaeologically during this specific building phase. The excavators suspect that after its destruction undamaged tools and moulds were recovered from the debris of the workshop (Hänsel/Medović 2004, 92). This would also imply ongoing metalworking activities and tradition. For the same reason, we cannot know for sure if the excavators' suggestion is valid that in the workshop there was no copper kept in stock (Hänsel/Medović 2004, 94). Even if 'customers' in fact supplied the copper, this does not guarantee that they were an elite group. From the variety of objects produced it is apparent that the needs of the local community in the widest sense were served, including ornaments and weapons or tools, none of which for themselves are particularly 'prestigious' objects (Kienlin 2007, 2–5, 13–16).

Summing up, it is suggested that the Feudvar workshop provides us with an example of intra-community metalworking 'specialisation', that may, upon full publication and exploration of the site, find its counterpart in other activities such as the making of pottery. For the Bronze Age tell at Százhalombatta, Hungary, it has been shown that the social boundaries between different 'crafts' such as pottery production and metalworking were fluid. Skills or knowledge were easily transferred between different domains of production, and cooperation was required (Sofaer 2006). Unfortunately, this finding is linked by J. Sofaer to the standard hierarchical model of Bronze Age society, which leads to the suggestion of a caste-like system of specialised craft production. One gets the impression that this is an attempt to improve the standing of those females involved in pottery making and wood working vis-à-vis male dominated metallurgy, within a traditional conception of a stratified society (Sofaer 2006, 137–140). Why not instead turn things upside down and stress the close links between metallurgy (and those male and/or female activities involved) and other 'specialised' crafts that require experience and skill, in order to scale down the importance traditionally attached to metallurgy (see also Kuijpers 2008, 52–53)? All such activities and their organisation are an expression of social complexity that must not be reduced to the question of political hierarchisation and the existence of craft specialists. Ethnography suggests that kinship groups such as lineages or clans may have an important part to play in the transmission of such 'special' knowledge from one generation to the next, and mobility if any may have been restricted. Possibly, it would have extended across the regional settlement group such as the Titel plateau, where Feudvar is situated, with its evidence of long-term cyclical change in settlement concentration and dispersal (Falkenstein 1998). Whoever practised metallurgy in the Feudvar workshop did so in a spatial and architectural setting that is suggestive of his/her integration in the local community. Contrary to the conclusion by B. Hänsel and P. Medovic (2004) it is likely that such integration would have extended beyond an individuals lifetime, but unfortunately from the excavated part of Feudvar we lack proof of the long-term stability of the local metalworking tradition. It is by indirect evidence such as the metallographic data, discussed in the following chapters, that we can infer such a model for the Bronze Age.

6
Early Bronze Age Metallurgy: A Review of the Evidence

The social organisation of mining and metalworking, their impact on society and the socio-cultural context, in which Bronze Age metallurgy developed, will be addressed in greater detail below (see chapter 8). To begin with, however, it is useful to provide a short review of the evidence at hand to outline the development of Bronze Age metallurgy and identify some of the topics that are controversial and require further discussion. The initial phases of the 'Bronze Age' in archaeological terms for large parts of south-eastern and central Europe are not identical with the earliest use of tin bronze. Rather this innovation is a somewhat later development that has to be understood in its respective culture setting and in relation to 'advances' in mining, smelting and alloying technique as well as in metalworking and exchange. By the end of the Early Bronze Age latest there clearly was an increase in the sheer quantity of copper available, and tin – typically from far abroad – was in common use for the production of a wide variety of bronze objects. This development is often reduced to the notion of inevitable 'progress', and in hindsight technological change attains a teleological quality. Instead, it can be shown that initially there were different trajectories. The acceptance of tin bronze in some areas was dependent on the complex interplay of many parameters, including local cultural attitudes to previously existing metalworking traditions and local preferences with regard to the practice of metallurgy and the objects produced. Other factors include the societies' ability to negotiate access to tin from abroad and geological constraints such as the availability of different types of copper that allowed for technological choice in the raw materials used. The acceptance of tin bronze in some areas was dependent on the complex interplay of many parameters: cultural such as previously existing metalworking traditions and local preferences with regard to the practice of metallurgy and the objects produced. Social such as the ability to negotiate access to tin from abroad and geological such as the availability of different types of copper that allowed for technological choice in the raw materials used.

6.1 Definitions and Chronology: The Early Bronze Age

Similar to the different usages of 'Eneolithic' and 'Copper Age' the term 'Early Bronze Age' throughout south-eastern and central Europe denotes quite different phenomena. Typically it is culturally defined rather than through metallurgy, as in its earliest stages it refers to groups that did not yet use tin bronze. This is most marked on the Balkans and in the Carpathian Basin where groups like Ezero (from c. 3100/3000 cal BC; Schwenzer 2005, 185–187), late Vučedol and Makó/Kosihy-Čaka (from c. 2600/2400 cal BC; Maran 1998, 347–351, 354, tab. 82) in local terminology constitute the beginnings of the Bronze Age (see fig. 2.3; Todorova 1981, 2–3 fig. 1; Tasić 1984; Bóna 1992). There is culture change to justify this view, with Ezero marking the end of the 'hiatus' or 'transition period' following the end of the Romanian-Bulgarian Copper Age (c. 3500–3100/3000 cal BC; Pare 2000, 2–3), Makó drawing on late Baden traditions and Vučedol influences (Bóna 1992, 11–12; Schreiner 2007, 89–90), and with a renewed increase in metallurgy and/or the deposition of metal after c. 3000/2800 cal BC that is linked to the appearance on the Balkans and in the Carpathian Basin of new types of single-edged copper shaft-hole axes, daggers and precious metal ornaments (fig. 6.1; e. g. axe types Veselinovo, Corbasca, Baniabic and Fajsz; Maran 1989;

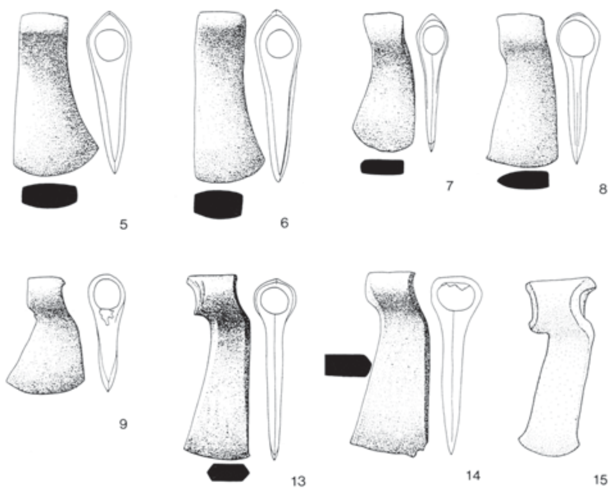


Fig. 6.1: Single-edged copper shaft-hole axes of the transition to the Early Bronze Age in south-eastern Europe (5–6: type Baniabic; 7–8: type Corbasca; 9: type Fajsz; 13–15: type Veselinovo II; after Parzinger 1993, tab. 208).

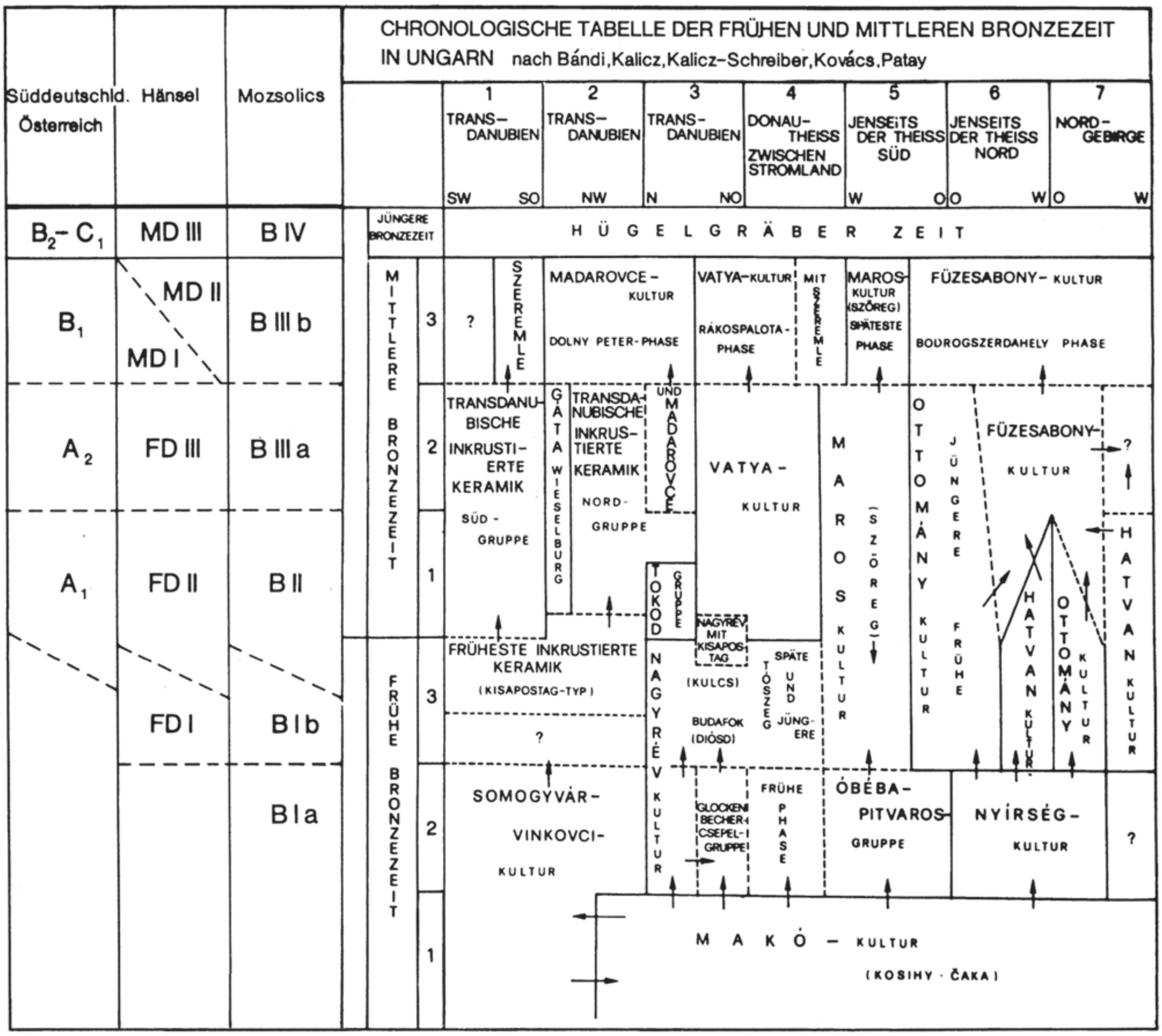


Fig. 6.2: Relative chronology and culture groups of the Early and Middle Bronze Age of the Carpathian Basin (Hungarian terminology; after David 2002, 34 fig. 2.8).

2001, 278–283; Parzinger 1993, 270–271 horizon 13, 348–351; Pare 2000, 12–13; Bátora 2003, 13–24).[7]

The axes in particular are thought to point east and to indicate, amongst other elements such as use of arsenical copper, that influence/people from the northpontic steppe regions were involved in culture change and metallurgy of this period (most recently: Harrison/Heyd 2007, 193–203; Schreiner 2007, 86–89). Arsenical copper certainly is not a good guide in this question having been used earlier as well and possibly deriving from various local ore deposits in central and south-eastern Europe instead of from the Caucasus (see above for the Pfyn, Altheim and Mondsee evidence; Matuschik 1998, 242–243). From the large Makó area, for example, very little in terms of copper artefacts is known, and metallurgy can only be said to have taken a rather slow rise with little socio-cultural impact. We should be wary of the concept of diffuse influences and migrations taking us back to early 20th century-type explanations of culture change.

The subsequent Early Bronze Age development of the Carpathian Basin provides an excellent example of the risks at hand (figs. 6.2 and 6.3). Makó gave way to a variety of Early Bronze Age groups such as Nagryrév, Hatvan, Somogyvár-Vinkovci or Maros (EBA II/III and MBA in Hungarian terminology; Tasić 1984; Machnik 1991; Bóna 1992; c. 2500–2200 cal BC and afterwards; Raczky/Hertelendi/Horváth 1992; Forenbaher 1993; David 2002, 3–46; Maran 1998, table 82). These are defined in particular by their different pottery styles, burial customs (inhumation vs. cremation) and by the beginnings of Bronze Age tell settlement (David 1998; Gogâltan 2005; in print). As late as the 1990s the explanation of this development involved multiple migrations and war (e. g. Bóna 1992; cf. Evans/

[7] Such axes and daggers are also known in silver and gold, e. g. from Velika and Mala Gruda, Montenegro; see Hansen (2001b, 13–33) and Primas (1995, 82–85; 1996, 75–112).

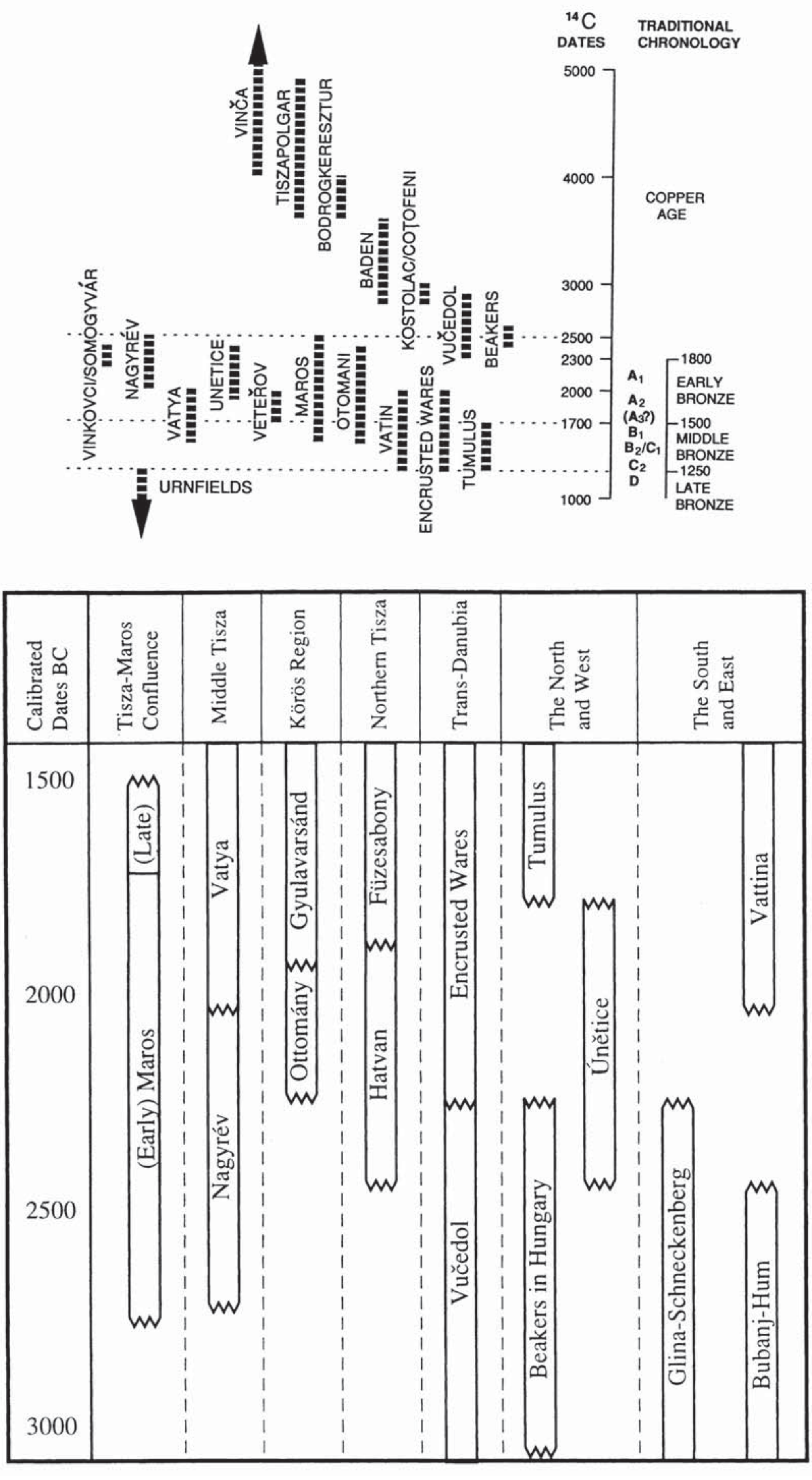


Fig. 6.3: Absolute chronology of the Eneolithic/Copper Age and the Bronze Age of the Carpathian Basin (after Forenbaher 1993, 236 fig. 2 [above]; O'Shea 1996, 36 fig. 3.3 [below]).

Rasson 1984, 718–719). Only more recently up-to-date reviews of the evidence became available (e. g. Vollmann 2005; Thomas 2008), and explanations of culture change shifted to the formation of regional identities expressed and negotiated through material culture (e. g. O'Shea 1996, 27–52, 353–369; cf. Bankoff 2004).

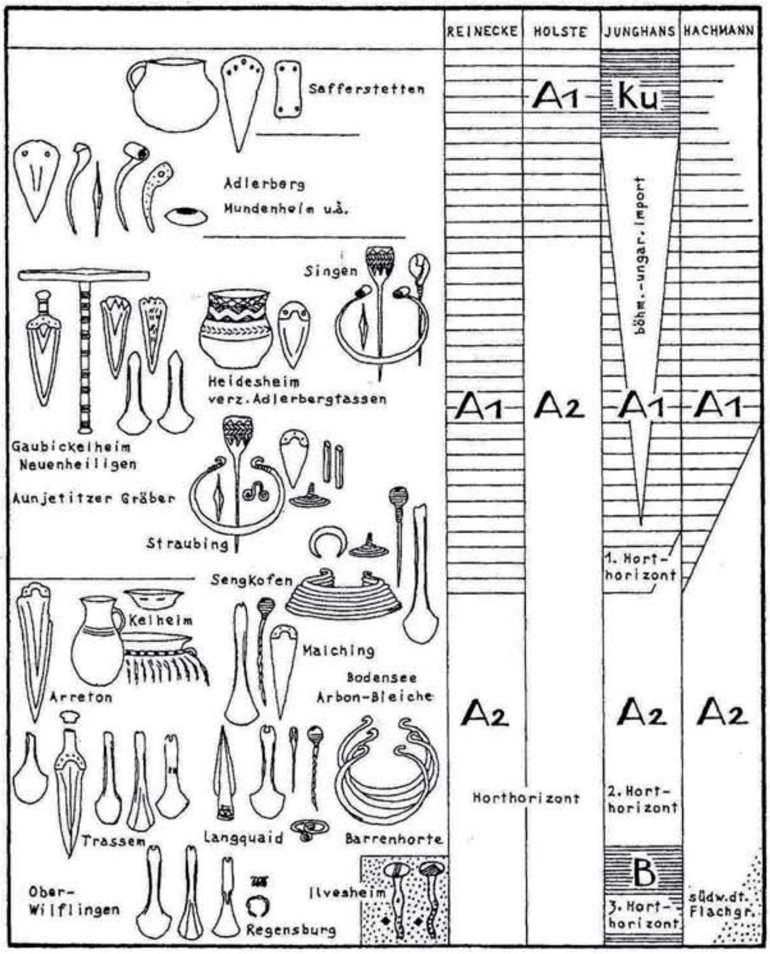
Further west in Slovakia and Austria this development is paralleled by the evolution of various regional groups of the Corded Ware and Bell Beaker cultures into Early Bronze Age groups proper. Among these there are Nitra and Unterwölbling that are followed up by Únětice, Wieselburg, Veterov and Mad'arovce etc., known mostly from cemeteries, hoards and – in the Veterov and Mad'arovce case – from (fortified) settlements (Neugebauer 1994, 49–144; Furmánek/Veliačik/Vladár 1999, 22–53; Bertemes/Heyd 2002; Krause 2003, 52–61). Various sub-groups of the Únětice culture represent the Early Bronze Age of a wide area from Austria north of the Dabube through Bohemia and Moravia to eastern Germany (e. g. Zich 1996; Bartelheim 1998; Lauermann 2003). In terms of the Reinecke chronology in use in central Europe these groups comprise the Early Bronze Age A1 and A2 (figs. 6.4 and 6.5; c. 2300/2200–1900/1800 and 1900/1800–1600/1500 cal. BC; Krause 1996; Rassmann 1996) which in the north alpine region of southern and south-western Germany is known mainly from cemeteries. Differences in burial customs are used to define regional groups such as Straubing, the Neckar group or Adlerberg (e. g. Krause 1988). From Lake Constance and various lakes of Switzerland there are lakeside settlements as well, that mostly start rather late during the Early Bronze Age, and typically date to about 1800/1700–1500 BC (based upon dendrochronological dates). The so-called Arbon group is defined by such settlement evidence, while the Swiss Aare Rhône and Saone Jura groups refer to burials (Hafner 1995).

In more general terms, the Early to Middle Bronze Age cultures of the Carpathian Basin, Early Bronze Age Únětice in north-eastern central Europe and the north alpine Early Bronze Age extending from Switzerland as far east as the Danube south of Budapest can be seen as three large culture areas divided by differences in artefact spectrum, burial customs and settlement patterns (fig. 6.6). Drawing on earlier beginnings in the Beaker period, all these groups are distinctly 'metal age' in that copper artefacts became increasingly widespread in burial ritual and hoarding. In some areas at least mining and metal production became of some importance. The precise way, however, in which tin bronze entered this system touches upon questions of both chronology and world view. The priority of the use of tin bronze in the eastern Mediterranean and the Near East is undisputed (see chapter 6.3). But did knowledge of this alloy subsequently spread along the classic Danube route to the Carpathian Basin and central Europe (e. g. Gerloff 1993, 83–86)? Was there an alternative and even earlier way along the Adriatic crossing the Balkans and the Alps (e. g. Maran 1998, 432–450)? Or was it the other way round with tin bronze first originating in western Europe, in Iberia and the British Isles, with a subsequent spread east to central and south-eastern Europe (Needham et al. 1989; Pare 2000, 25–27)?

6.2 Bronze Age Mining in Central Europe

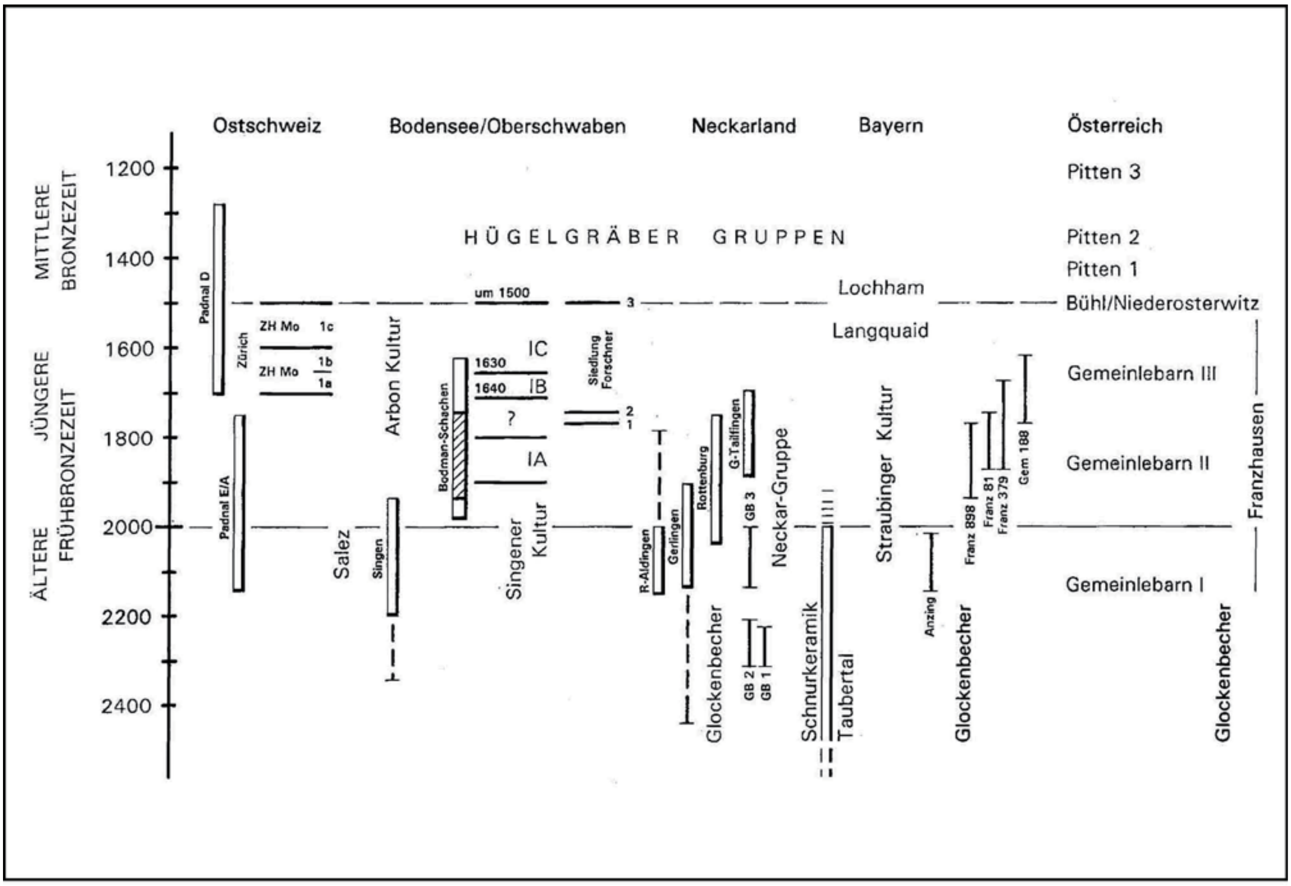
Unlike western Europe with its well attested exploitation of mining districts such as Ross Island, Mount Gabriel or the Great Orme on the British Isles and Cabrières in southern France (O'Brien 1994; 2004; Groer 2008; Ambert et al. 2009) in central Europe evidence for 3rd and early 2nd millennium BC copper mining and production is for its most part circumstantial. Apart from a number of smaller copper sources from which little is known in terms of prehistoric working (e. g. Boroffka 2009b for Romania), the Alps and the German and Slovakian Ore Mountains have traditionally received most academic attention. This is due in large part to their substantial copper ore deposits which we know to have been exploited in medieval and early modern times (fig. 6.7; e. g. Otto/Witter 1952; Pittioni 1957; Bartelheim/Niederschlag 1998; Stöllner 2009; Oeggl/Prast 2009; cf. Harding 2000, 206–217; Bartelheim 2009, 177–180). At some stage for each of them analytical evidence of Bronze Age exploitation has been claimed, but has not been universally accepted. Currently this issue is re-examined by large-scale lead isotope analyses (LIA) projects for the first time (e. g. Höppner et al. 2005; Schreiner 2007; Oeggl/Prast 2009). Early Bronze Age groups more or less rich in copper and bronze objects from their graves and hoards are situated in both the alpine foreland and in the vicinity of the German and Slovakian Ore Mountains (see above). This coincidence has been taken to imply both the Bronze Age exploitation of adjacent ore deposits as well as wealth and/or power derived from metallurgy and control of exchange of its products (e. g. Menke 1978/79; Krause 1988). Only recently a more reluctant view has been expressed, by reference to the fertile soils and salt springs of the central German Únětice culture area that suggest alternative avenues to 'wealth' and perhaps to 'power' (e. g. Bartelheim 2002). Similarly, numerous hoard finds in the alpine foothills of up to several hundred *Ösenringe* and rib-shaped ingots certainly imply Early Bronze Age mining in the eastern Alps (fig. 6.8). However, Ösenringe have a wider distribution, and they only provide a weak hint at the exact location and organisation of mining activities, nor do they rule out an important contribution of the Slovakian Ore mountains either.

The Alps were part of Neolithic subsistence strategies (e. g. transhumance) and also raw material procurement, for example the quarrying for jadeite in the western Alps used for prestigious axes widely distributed as far as Brittany (Della Casa 1999; 2005; Pétrequin et al. 2005; 2006; Pearce 2007). The interpretation of these activities is typically modelled upon ethnographic case studies of seasonal mining activities (e. g. Pétrequin/Pétrequin 1993) and differs markedly from the models advocated in Bronze Age research. Pollen diagrams and scant archaeological evidence indicate that the lower, northernmost part of some of the alpine valleys was colonised in the late 3rd



Bayern	S-Bayern	Österreich	Österreich	Karpatenbecken	Mad'arovce-	Gemeinlebarn		
Torbrügge 1959	Ruckdeschel 1978	Schubert 1974	Mayer 1977	Hänsel 1968	Věteřov- (Böheimkirchen)	Gräberfeld A	E,F	27/2
B	B	Sichelnadeln	Lochham-Wetzleinsdorf	MD II	Spät-			
A_2	A_{2c}	4	Bühl-Niederosterwitz	MD I	Klassisch-			
	A_{2b}		Gemeinlebarn III/ Langquaid	FD III	Früh- (Spätaunjetitz Übergang)			
	A_{2a}	3	Gemeinlebarn II	FD II				
A_1	A_{1b}							
	A_{1a}	2	Gemeinlebarn I	FD I				
		1	Glockenbecher					

Fig. 6.4: Relative chronology of the central European Early Bronze Age (after Torbrügge 1961, 819 fig. 1 [above]; Neugebauer 1991, 51 fig. 9.1 [below]).



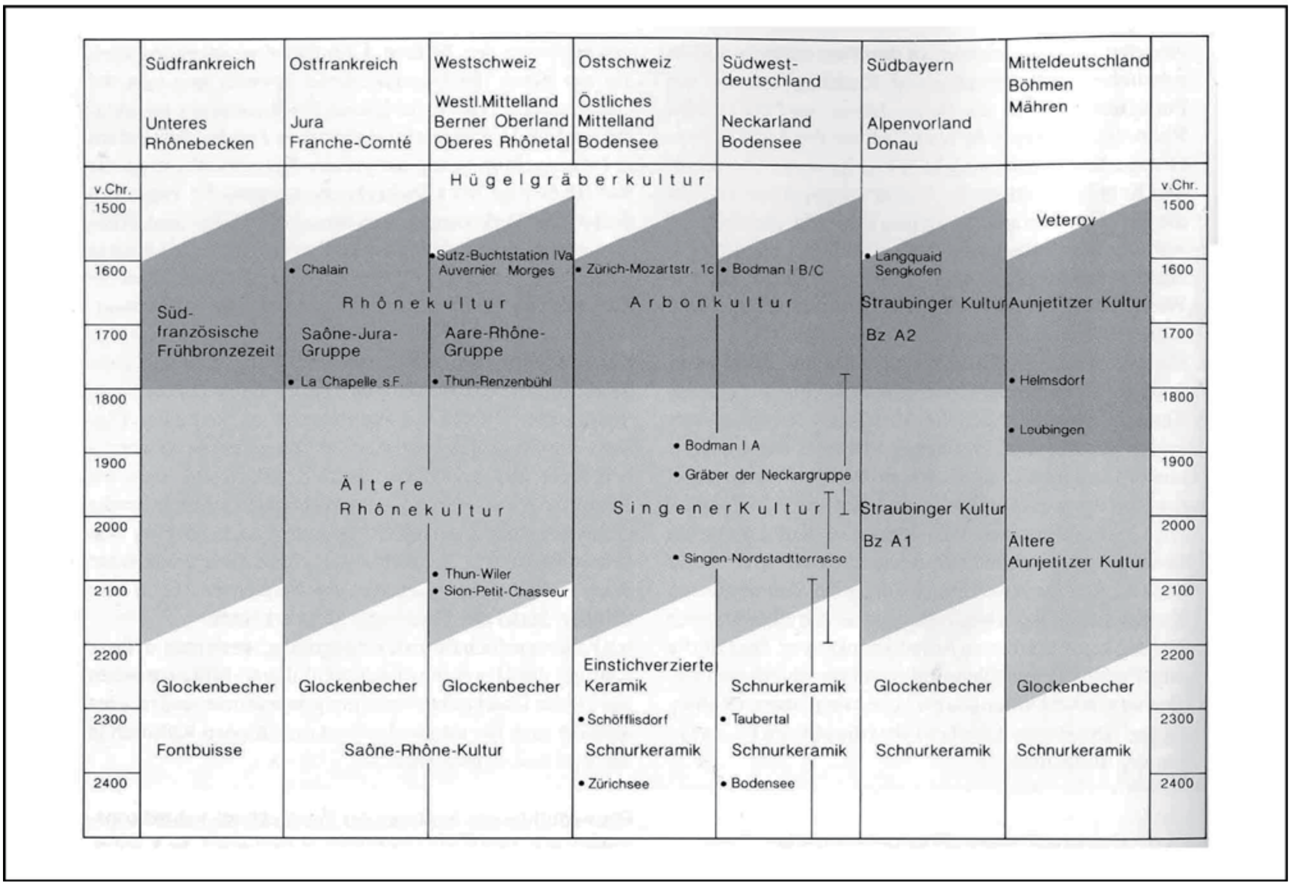


Fig. 6.5: Absolute chronology and culture groups of the central European Early Bronze Age (after Krause 1996, 79 fig. 5 [above]; Hafner 1995, 178 fig. 90 [below]).

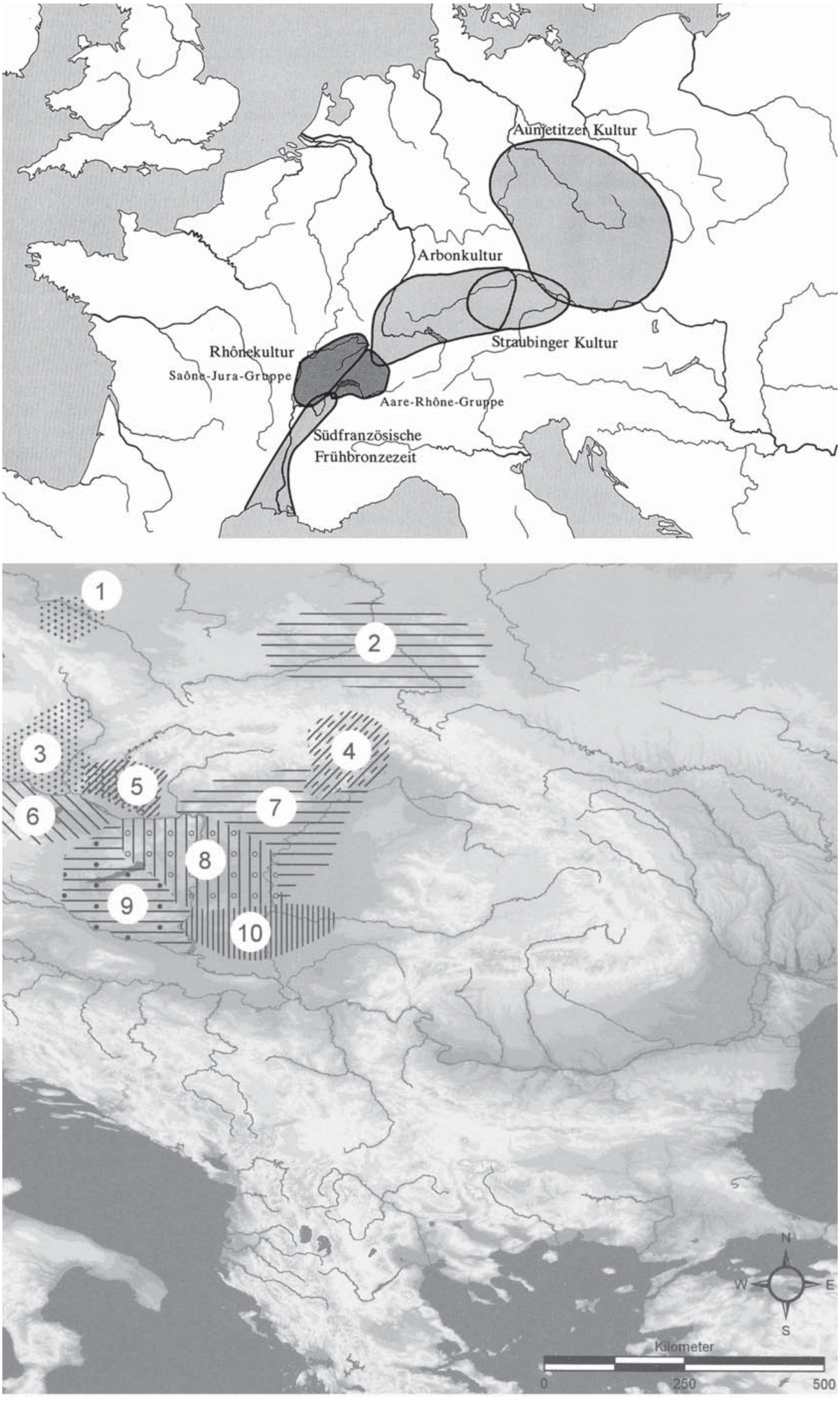


Fig. 6.6: Maps of the Early Bronze Age groups of central Europe (after Hafner 1995, 182 fig. 92) and the Carpathian Basin (1 and 3: Únětice groups; 2: Mierzanowice; 4: Košťany; 5: Nitra; 6: Leitha/Unterwölbling; 7: Hatvan; 8: Nagyrév; 9: Kisapostag; 10: Maros; after Schreiner 2007, 104 fig. 4.15).

Fig. 6.7: Map of the most important copper and tin deposits in central Europe (after Krause 2003, 30 fig. 7).

millennium BC. But only in the second half of the Early Bronze Age after c. 1800/1700 cal BC is there evidence of permanent settlement extending well into the Alps (Schmidl et al. 2005, 459–462; Krause 2005a, 396 fig. 5; Primas 2009, 190–191, 196–199; Kienlin/Stöllner 2009). There is a marked discrepancy, therefore, between the lack of alpine settlement and the use of alpine (Singen type) fahlore copper right from the start of the Early Bronze Age (c. 2200 cal BC). This mineral is thought to have been mined somewhere in mining districts along the alpine valley of the river Rhine and its tributaries (Krause 1988; 2003). Most likely, small-scale exploitations – evidence of which is still missing – was carried out on a seasonal basis by mobile members of lowland communities, and it formed part of a broader pattern of pastoral/transhumant land-use extending into the Alps (see chapter 8).

Exactly how this pattern evolved into permanent settlement of the alpine area after c. 1800/1700 cal BC, and the role of metallurgy in this process is subject to debate (e. g. Shennan 1995; Krause 2005a; Bartelheim 2007). In addition, we are not equally well informed on early mining and copper production in the western and the eastern Alps, and most unequivocal evidence of extractive metallurgy comes from somewhat later times. In Switzerland, for example, so far there is no evidence at all of Bronze Age copper mining or smelting furnaces, and radiocarbon dated slag heaps relate to Late Bronze Age and Iron Age activities only (Fasnacht 2004; Wyss 2004). The same is still true of the alpine Rhine valley and Montafon area in Austria where recently the search of Bronze Age mines has been intensified (Krause 2005a; 2005b). In the eastern Alps, on the other hand, there are the famous Mitterberg area (fig. 6.9) and the Paltental mining district with extensive evidence of Middle to Late Bronze Age mining (e. g. Presslinger/Eibner 2004; Stöllner/Eibner/Cierny 2004). Both elaborate deep-mining and open-cast mining (*Pingenbau*) were practiced, typically exploiting sulphidic chalcopyrite copper ores. Smelting these minerals produced the so-called east alpine copper (*ostalpines Kupfer*) that from the second half of the Early

Fig. 6.8: The distribution of Early Bronze Age Ösenringe (below) and an Ösenring hoard from Pfedelbach, Germany (after Gerloff 1993, 64 fig. 2 [below]; Krause 2009, 52 fig. 5 [above]).

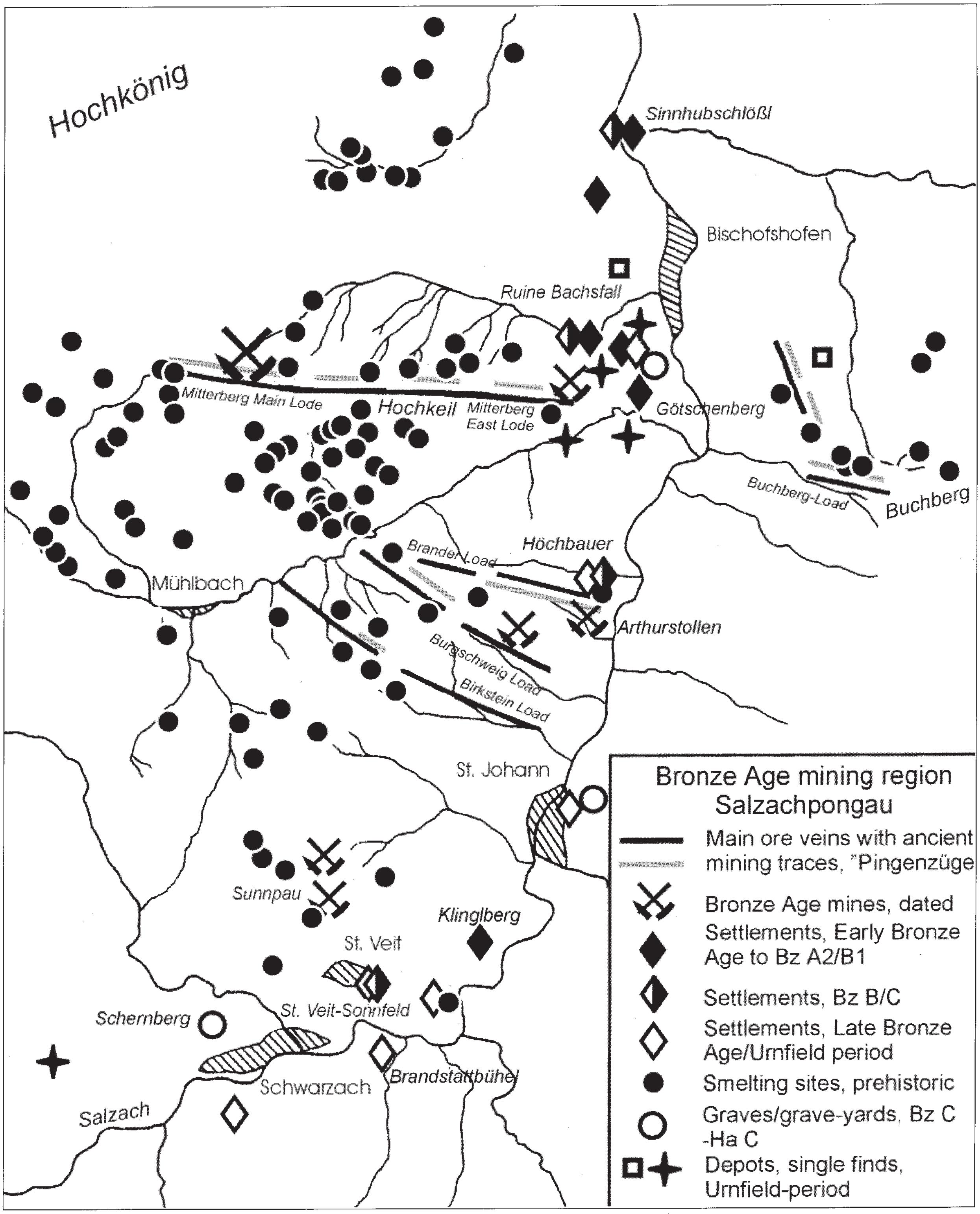


Fig. 6.9: Map of the Mitterberg area with evidence of Bronze Age mining, smelting and settlement (after Stöllner 2003, 434 fig. 11).

Fig. 6.10: Two Middle Bronze Age smelting furnaces from northern Tyrol, Austria (after Goldenberg 2004, 172 fig. 11).

Bronze Age onwards replaced the earlier fahlore type copper (Krause 2003, 166–169; for a later return to fahlore copper see Rychner 2004; Sperber 2004). Copper production in substantial furnaces became increasingly standardised, resulting in the specific eastern alpine tradition of multi-stage roasting and smelting already mentioned above (the Mitterberg process). There is evidence for this process from a large number of Middle to Late Bronze Age copper production sites in the eastern Alps (fig. 6.10) often situated in the vicinity of potential ore outcrops (e. g. Herdits 2003).

The evidence of Early Bronze Age mining and metallurgy, on the other hand, is much less clear and typically comes from the earliest settlements established towards the end of the Early Bronze Age and during the early Middle Bronze Age (see above; after c. 1800/1700 cal BC). The well-known site of St. Veit-Klinglberg in the inner alpine part of the Salzach valley is one of these (see fig. 6.9; Shennan 1995), other examples include the Buchberg near Wiesing in the lower Tyrolean Inn valley (Martinek/Sydow 2004), Savognin-Padnal and Savognin-Rudnal in the western Alps in the Swiss canton Graubünden (Rageth 1986; Wyss 2004) and – with the most recent excavations – the Bartholomäberg in the central alpine Montafon region (Krause 2005a). From Buchberg there is evidence of on-site smelting of fahlore minerals from neighbouring ore deposits in a one-step process without roasting. Apparently smelting was carried out in open hearths leaving little archaeological traces apart from some slag (Martinek/Sydow 2004, 206–208; Höppner et al. 2005, 300–301). This might explain why from some other sites evidence of smelting is controversial and not easily distinguished from the remains of casting and metalworking also attested in some of these settlements. However, at least in the eastern Alps smelting slag was widely used as a temper in pottery thus providing indirect evidence of extractive metallurgy (e. g. Shennan 1995, 147–175). In technological terms the processes involved were simple and had not yet reached the standardisation apparent somewhat later in the Middle and Late Bronze Age. In organisational terms unlike later metallurgy both copper production and working were still practiced in the settlements or their immediate surroundings.

Typically, these sites are rather small, situated on hilltops and some show signs of fortification. In addition, some but by no means all were drawing upon neighbouring ore deposits, for example St. Veit-Klinglberg where there is evidence of food brought in from outside to support a mining population (Shennan 1995, 284–285). For this reason in the standard model of Early Bronze Age alpine settlement they are interpreted as central places in control of smaller neighbouring sites in what is conceived of as a hierarchical settlement system (Krause 2005a; 2007). Although, for instance from Bartholomäberg there is no

Fig. 6.11: Map of the major tin deposits in Europe.

evidence of metallurgical activities (Krause 2005a, 405) it is supposed that power was derived from control over the exploitation of copper ore deposits in the vicinity and the exchange of copper. Early mining and metal production, from this perspective, is a complex technology requiring organisation and control exercised by emergent Bronze Age elites. The move into the Alps itself is seen as a consequence of growing need for copper (e. g. Strahm 1994, 2–5; Krause 2003, 257–262; 2005a, 408–409).

An alternative approach was suggested in S. Shennan's (1995, 300–308) study on St. Veit-Klinglberg, which was conceptualised as a mining settlement operating largely autonomously without centralised control. From a formalist perspective this usefully deconstructs the controversial emphasis on elites and metallurgy of the 'standard' model – Shennan's (1993, 59) 'myth of control'. It is unclear, however, if the notion that mining offered hitherto unknown potential for individual ambition and ways to break through traditional social boundaries by acquiring metal and wealth in fact applies to prehistoric society. Moreover, we have to ask if copper was the main economic reason for colonisation of the Alps at all. A detailed review of the earliest settlement evidence suggests a much more nuanced picture and most likely different alpine areas and valleys followed different trajectories with regard to early mining and metal production (see chapter 8; Kienlin/Stöllner 2009).

6.3 Bronze and the Bronze Age

Unlike arsenical copper, tin bronze with tin contents in excess of about 2 % to 3 % is a true alloy since in the Old World there are few occurrences of both copper and tin minerals that upon co-smelting would have produced an unintentional copper-tin 'alloy' (among the few possible exceptions are Iberia and central Asia: Rovira/Montero 2003; Ottaway/Roberts 2008, 208–209). Copper ore deposits (see above) are far more common in fact than occurrences of tin (fig. 6.11; Harding 2000, 197–201). The most well-known are located in Cornwall and the Ore Mountains (*Erzgebirge*) in German Saxony and Czech Bohemia (Muhly 1973; 1985; Roden 1985; Penhallurick 1986; Bartelheim/Niederschlag 1998; Pernicka 1998; Niederschlag et al. 2003; Giumlia-Mair/Lo Schiavo 2003; Haustein/Gillis/Pernicka 2010). Additional ones are known from the Iberian Peninsula, Brittany and the French Massif Central, Tuscany and Sardina but their prehistoric exploitation is even more controversial than in the Cornwall and *Erzgebirge* case.

Many debates on Bronze Age communication and trade therefore go back to the question of tin supply for what was to become the standard alloy of this period, and to the amazing fact that the earliest tin bronzes after c. 3000 cal BC appeared in northern Mesopotamia and Anatolia

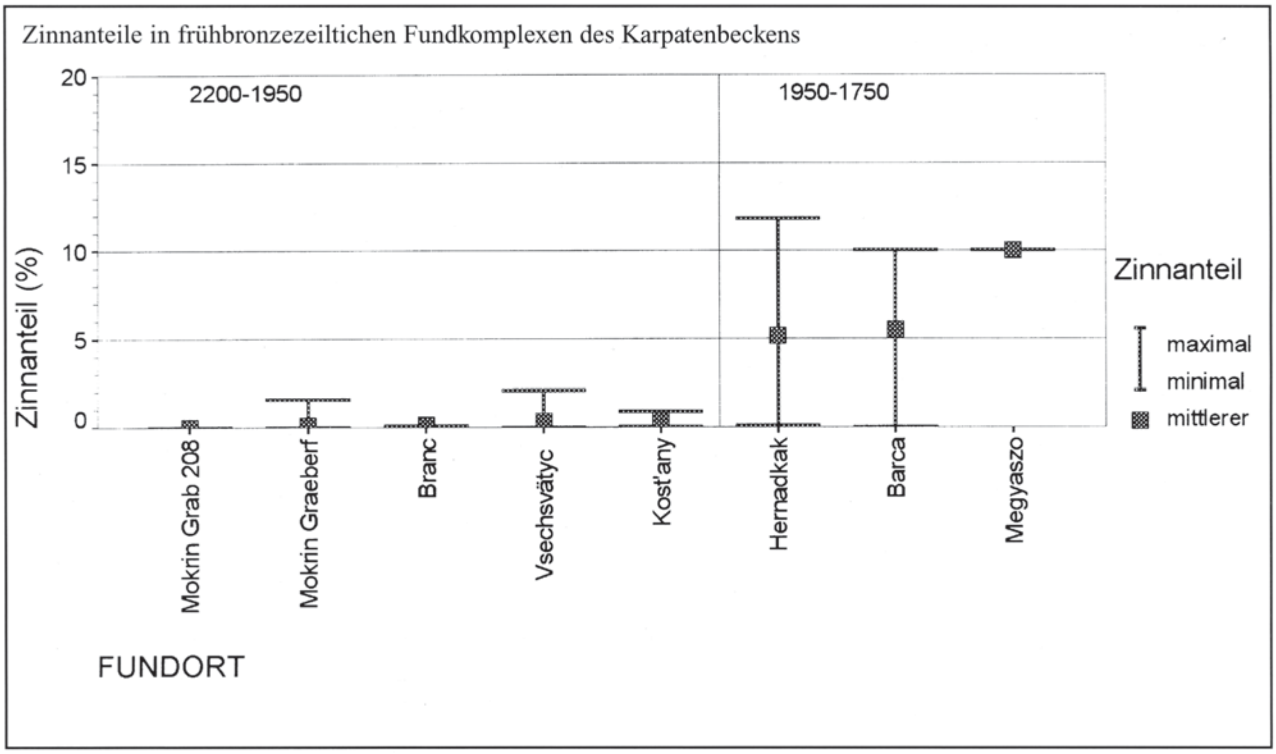


Fig. 6.12: The development of tin contents and the introduction of tin bronze in the Carpathian Basin (after Müller 2002b, 274 fig. 8).

– an area devoid of tin sources of its own (Pernicka 1998; Weeks 1999; 2004; 2007; Pare 2000; Pernicka et al. 2003; Yalçin/Özbal/Paşamehmetoğlu 2008; for Kestel debate see e. g. Muhly 1993). Only somewhat later by the middle of the 3rd millennium BC, was a more regular use made of bronze in the Near East and the Aegean, typically for prestigious objects first (see also Nakou 1995; Gillis 1999a; 1999b). Traditionally, the ancient civilisations of this area were thought to have drawn upon tin deposits either on the British Isles or in the German Ore Mountains (e. g. Gerloff 1993, 83–86). Radiocarbon dating necessitated a review of these far-ranging contacts (most recently: Gerloff 2007) and resulted in a more nuanced picture of pre-Bronze Age and Early Bronze Age exchange systems. These are thought to have extended along the Danube and/or the Adriatic and across the Balkans towards the Carpathian Basin and central Europe (for the most profound discussion of chronology and attempt at modelling this exchange network see: Maran 1998, 432–450). Interestingly, while authors working in this area consider western tin sources one of the possible causes of contact and exchange (e. g. Gerloff 1993, 85–86; Maran 1998, 439–443, 449–450; an argument in favour may in fact be a tin bronze knife from Velika Gruda: Primas 1996, 97–104; 2002, 304–305), lead isotope analyses show that at least the mid-3rd millennium BC increase in Aegean tin bronze metallurgy was most likely supported by copper and tin ultimately imported from as far east as Central Asia (e. g. Boroffka et al. 2002; Parzinger 2002; Pernicka et al. 2003, 160–172; Parzinger/Boroffka 2003).

This finding might explain why apart from some early finds such as Velika Gruda the regular use of tin bronze in south-eastern Europe is a relatively late phenomenon (Liversage 1994, 75–92; Schalk 1998, 125–127; Pernicka 1998, 138–141; Pare 2000, 12–18; Primas 2002, 307–308; Müller 2002b, 273–275 fig. 8). In consequence, it has been suggested that since there is better evidence for early low-tin bronzes in Beaker contexts than in local Early Bronze Age ones, this technology might reflect western influences instead of transfer along the Danube route (Liversage 1994, 96–97; Pare 2000, 17). In Bulgaria, Romania and the former Yugoslavia regular use of high-tin bronze is only attested from the local Middle to Late Bronze Age, after c. 1700/1600 cal BC (Pare 2000, 12–16). Similarly, in the Carpathian Basin in early cemeteries such as Mokrin or Branč there is little evidence for the use of tin bronze prior to c. 1900/1800 cal BC (fig. 6.12; Pare 2000, 16–18, 26 fig. 1.14; Müller 2002b, 274 fig. 8; cf. Liversage 1994). In the Slovakian cemetery of Jelšovce it is only in the later graves that tin bronze became the standard alloy (Bátora/Pernicka 1999; 2000; Bátora 2000), and the same is true for the north alpine region where bronze was widely used only in EBA A2 after about 1900/1800 cal BC (Krause 2003, 213–222). Thus, in central and south-eastern Europe the move to tin bronze was a gradual process that only came to an end well in the 2nd millennium cal BC. In western Europe, on the other hand, tin bronze is well attested somewhat earlier at about 2200–2000 cal BC (fig. 6.13). Apparently its introduction took place in a rather short period of time, drawing on local placer deposits in south-western Britain (Pare 2000, 20–22, 26 fig. 1.14). Given the evidence of early contacts between the British Isles and the continent (e. g. Jockenhövel 2004; Fontijn 2009) it is possible that the knowledge of tin bronze was in fact a western European

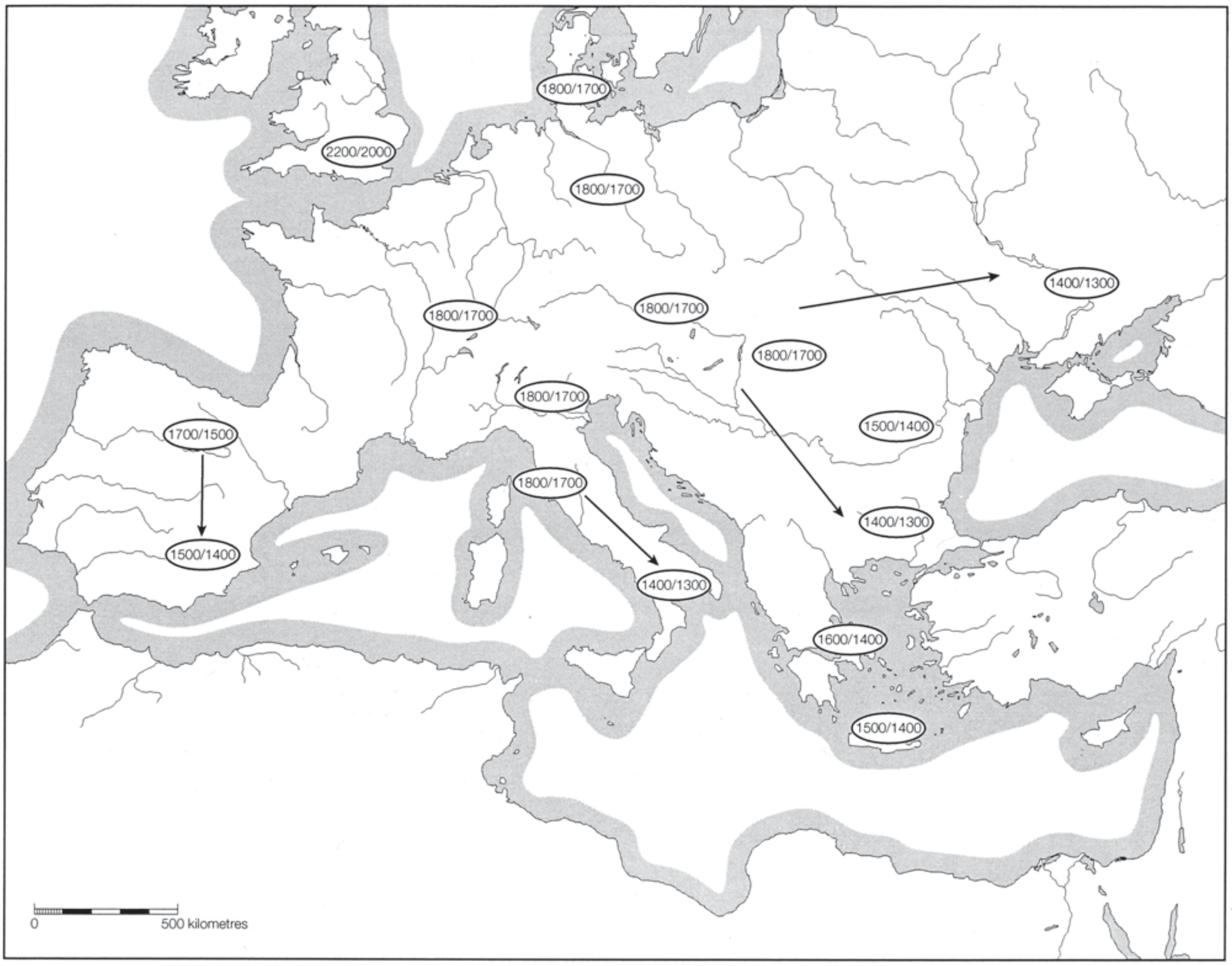


Fig. 6.13: Map indicating the approximate dates of the transition to the use of tin bronze in Europe; note the early occurrence of bronzes on the British Isles (after Pare 2000, 26 fig. 1.14).

innovation that subsequently spread east – somewhere, perhaps, to meet eastern influences reflecting the longer tradition tin bronze had in the Near East and in the Aegean.

The overall situation, however, is still unclear due to a lack of analytical data from some areas, chronological problems and the open question of the potential Early Bronze Age exploitation of central European tin sources. This can best be illustrated by reference to the Únětice culture. From both the German and the Slovakian Ore Mountains there is still no conclusive evidence of Bronze Age tin production (Bartelheim/Niederschlag 1998; Niederschlag et al. 2003; Schreiner 2007). Even in Cornwall, however, the low archaeological visibility of tin panning from alluvial deposits (as opposed to proper mining) poses problems, so the central European Ore Mountains might nonetheless have been a source of Bronze Age tin. On this basis there was agreement for some time past that the Únětice culture was most likely an early centre of tin bronze production and the accompanying development of improved casting techniques (most recently: Müller 2002b, 276–277; Krause 2003, 84 fig. 34, 243–249, 263–265). This view received support from radiocarbon dates indicating that elaborate forms such as halberds and solid-hilted daggers made their first appearance prior to c. 2000 cal BC in the Únětice culture (fig. 6.14). In addition, analytical evidence proved a strong metallurgical tradition within what later became the Únětice area of both the exploitation of sulphidic copper ores (fahlore type copper) and the occasional occurrence of low-tin bronze reaching back into the local Neolithic (Krause 2003, 212–213, 241). This position was challenged only recently when the early radiocarbon dates for the Melz II hoard in Mecklenburg-Vorpommern, Germany, were called into question, and an alternative model of the origin of solid-hilted daggers in Italy and the western Alps was advanced (fig. 6.15; Schwenzer 2002; 2004, 238–245).

For the time being the question of tin bronze origins and the role of the Únětice culture is open again. However, it is important that the influence of our peculiar perception of metallurgical 'core areas' and foreign influences on such discussions be noted, as the shift away from Únětice as a largely autonomous centre of Early Bronze Age (tin bronze) metallurgy owes more to an alternative grand narrative gaining acceptance than to any changes in the actual data available. Knowledge of tin bronze and complex casting techniques is now derived from an Adriatic exchange system extending across the (western) Alps to central Germany

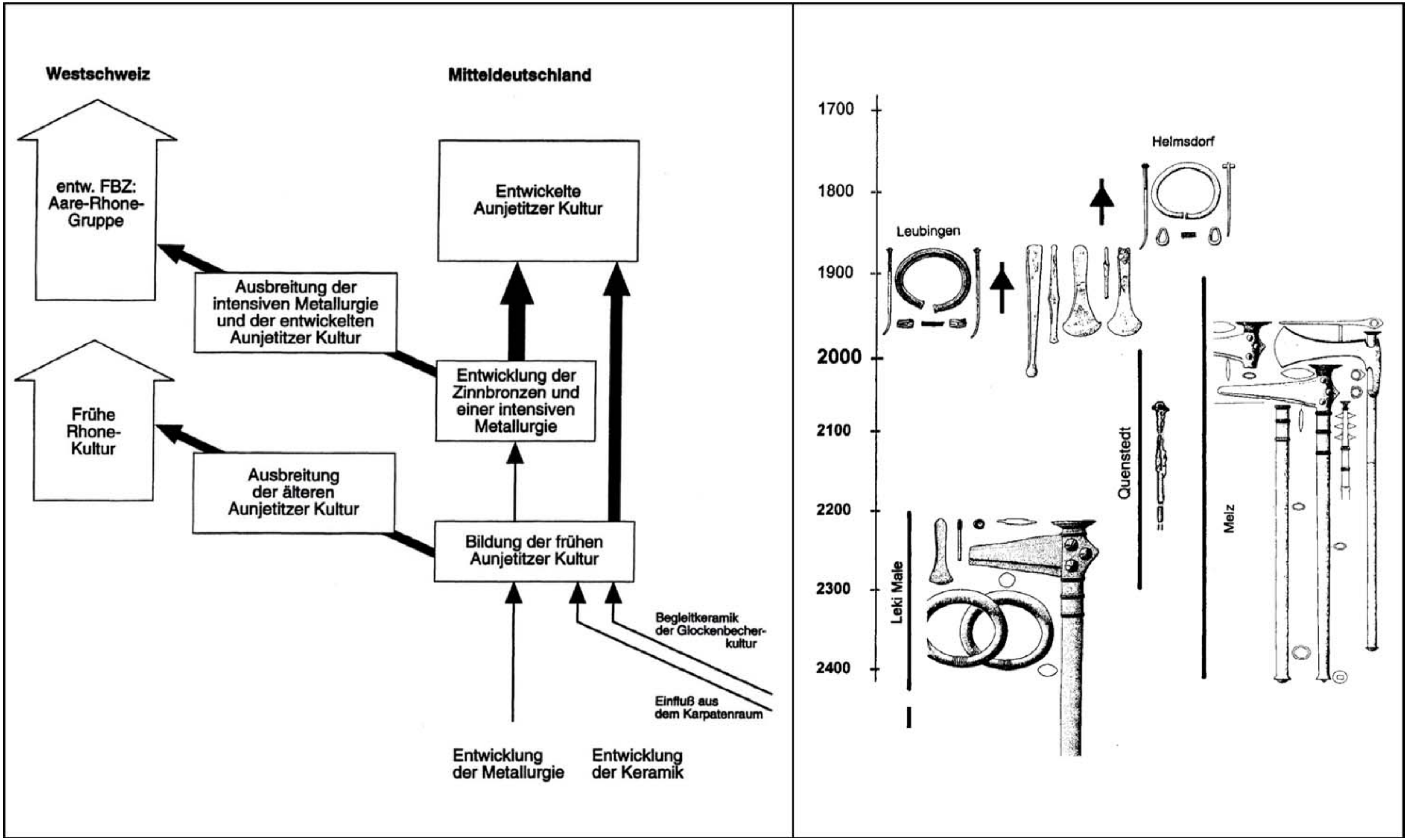


Fig. 6.14: Previously accepted evidence (radiocarbon and dendrochronologically dated finds) for the early occurrence of tin bronze and complex casting techniques in the Únětice culture (right) and a model of the influence Únětice metallurgy supposedly had on the north alpine region (after Krause 2003, 81 fig. 32, 249 fig. 227).

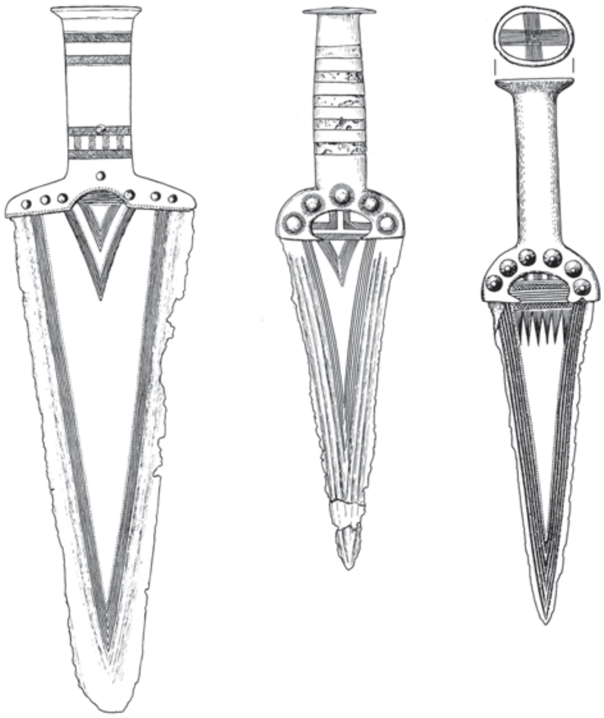


Fig. 6.15: Early Bronze Age solid-hilted daggers (from left to right: Oder-Elbe type, Alpine type and Rhône type; after Schwenzer 2004, 44 fig. 24, 65 fig. 41, 70 fig. 45).

(fig. 6.16), thereby ultimately transferring metallurgical innovation back to the Bronze Age Aegean. Evidence in favour of this position, such as supposedly early dates from the western Alps and an unproven tin source in Tuscany, is no stronger than the case for Únětice. However, the new model successfully realigns the diffusion of tin bronze with the postulated spread of rank society that is traced from the Aegean via the Adriatic and the Bronze Age Kastelliere of Istria (e. g. Hänsel 2002) to the Alps and central Europe (e. g. Krause 2005a, 408–409; 2006/07, fig. 14).

6.4 Copper and Bronze: Technological Choice in EBA Metallurgy

Tin ore was most likely won from alluvial deposits from streams carrying tin oxide minerals. These might have been used directly to produce bronze by co-smelting with copper ores or by adding tin oxide to molten copper under reducing conditions. This process might account for highly variable tin contents at the beginning of the Early Bronze Age. But latest when tin contents stabilised in the 8–12 % range (10 % typically given in the literature is an idealized value, hardly achieved in practice) it is more likely that metallic tin was produced first and added to the liquid copper (Muhly 1973; Penhallurick 1986; Ottaway 1994, 138–140; Pernicka 1998; Bachmann 2004). Metallic tin is

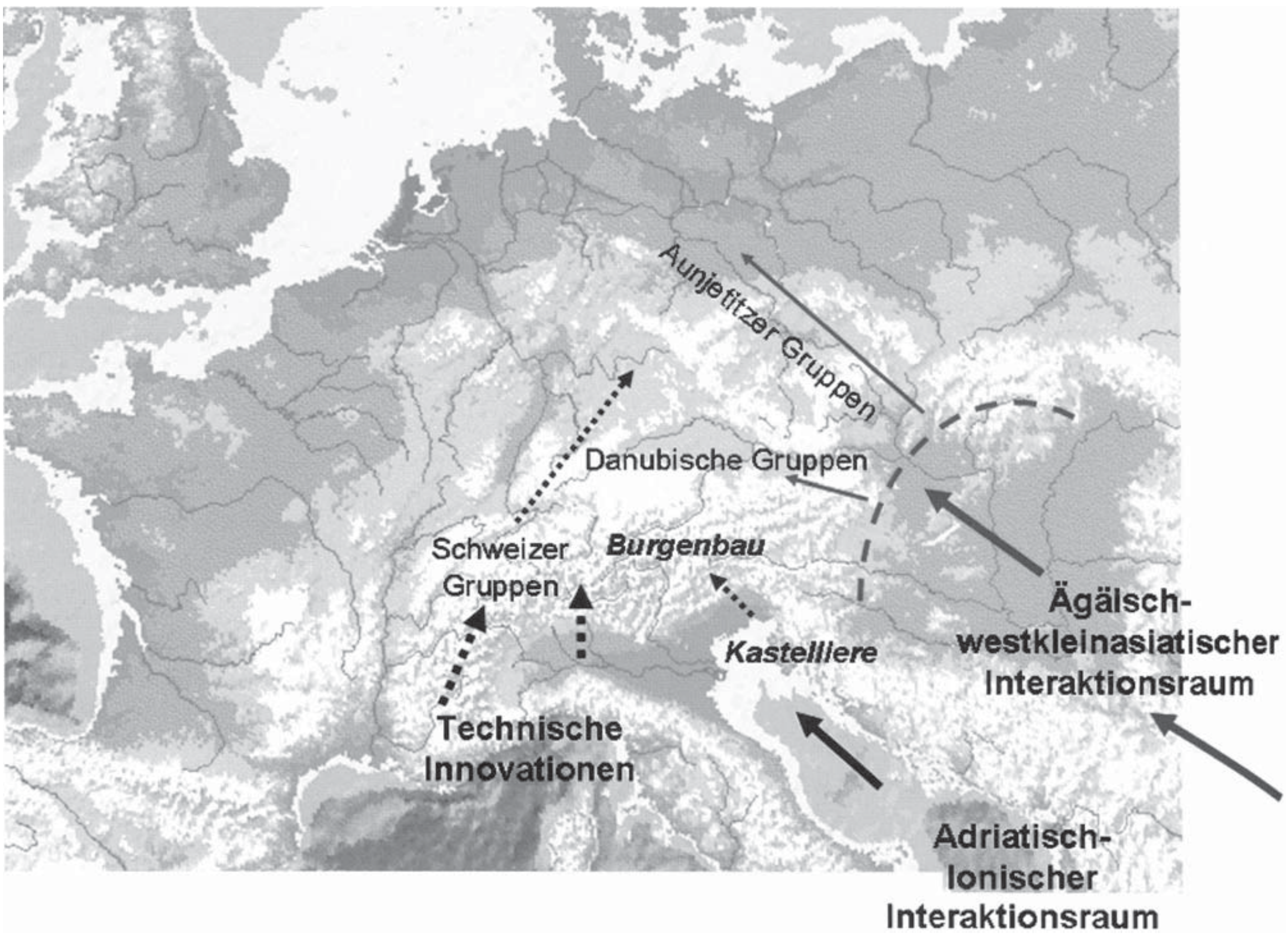


Fig. 6.16: Modell of the spread of metallurgical and other innovations via the Carpathian Basin and the Adriatic to central Europe during the Early Bronze Age; note the reversed connections supposed between the alpine area and the Únětice culture when compared to fig. 6.14 (after Krause 2006/07, 62 fig. 14).

apt to decompose at low temperatures. This is why very few tin artefacts or ingots are known from prehistoric Europe, notable exceptions including the tin beads from a grave in Buxheim, Bavaria (Möslein/Rieder 1997) and, of course, the tin ingots from the famous Ulu Burun ship wreck off the Turkish coast that provide evidence of Late Bronze Age bulk trade in metals and other commodities in the eastern Mediterranean (Pernicka 1998; Pare 2000; Yalçın/Pulak/Slotta 2005; Ottaway/Roberts 2008, 207–209).

Tin bronze is thought to be superior to copper for a number of reasons: among them its lower casting temperature, its better casting properties, its colour (see above for the early use of tin bronze for prestigious objects in the Near East) and its higher hardness both in the as-cast state and after working. However, often such arguments fall short of the actual compositions used. For example, levels of 10 % tin are required to have a significant effect on the casting temperatures but such a concentration is rarely reached in the earliest tin bronzes. There are strong evolutionist notions involved in the interpretation of tin levels in bronze. While early low-tin bronzes in the 2–6 % range tend to be seen as a result of poor initial control over the alloying process or problems with access to tin, the overall direction of technological progress is thought obvious and directed towards the superior alloy – high-tin bronze (for a more detailed discussion of this issue see chapter 7.5; Kienlin 2008a, 251–280). This trend is certainly true in retrospect, and eventually tin bronze became the standard alloy of the European Bronze Age. But in many parts of the Old World bronze did not replace copper for a considerable period of time indicating that its adoption was "a cultural choice, not a product of technological determinism" (Pare 2000, 25; see also Sofaer-Derevenski/Sørensen 2002). This is true wherever arsenical copper was in widespread use, offering a serious alternative to tin bronze (see Lechtman 1996 for a comparison of their properties), for example in the Aegean or Iran where arsenical copper and bronze coexisted for a long time (e. g. Pigott 1999; Thornton/Rehren/Pigott 2009; Thornton 2010; cf. Roberts/Thornton/Pigott 2009, 1015, 1017–1018).[8] Less attention is paid in this context to fahlore copper rich in a number of different trace elements such as arsenic, antimony, silver and nickel derived from sulphidic copper ores, although it was widely used during the Early Bronze Age from the western Alps to the Baltic Sea as well as into the Carpathian Basin to the east. Best known as 'Singen' copper after its occurrence in an EBA cemetery close to Lake Constance (Waterbolk/Butler 1965, 235; Krause 1988, 184) this is actually a group of closely related copper types most likely originating from the exploitation of similar ore deposits in the Alps, the German Ore Mountains as well as the Carpathians by the use of a comparable smelting technique (Krause 2003, 122, 157–160; Rassmann 2005). Both in functional and symbolic terms of mechanical properties and colour, fahlore copper rivalled tin bronze (see also Moesta 2004). Drawing on metallographic data from artefacts found in the surroundings of the eponymous Singen cemetery it will be shown below that fahlore copper in some regions offered an alternative trajectory to the reliance on tin from abroad. It caused considerable distortion in what is often perceived of as the rapid and uniform spread of tin bronze (see chapter 7.3; Kienlin 2008a, 121–155; for another example – the so-called *Ösenring* copper, i. e. fahlore copper without nickel, that was predominantly used in looped rings/ingot torques and *Spangenbarren* – see Butler 1978; 2002; Krause/Pernicka 1998; Junk 2003).

[8] For a possible example to the contrary – tin bronze replacing arsenical copper rather quickly – see the British Isles (Needham et al. 1989; Pare 2000, 20–22); note however that in the meantime a more gradual shift and earlier beginnings of the use of tin bronze is also envisaged for the British Isles (Bray in print).

7
Traditions under Transformation II: Technological Choice in Bronze Age Metallurgy

It was only during the Early Bronze Age that tin bronze gradually took the place of pure copper, arsenical copper and fahlore copper in the production of various types of artefacts. This process occurred because of the exploitation of different ore deposits and the availability of tin, which in this period was either derived from the German or Slovakian ore mountains or was imported from outside central Europe, most probably from Britain. With regard to this phase of Early Bronze Age metallurgy the problem of copper and tin origins has long been investigated with the help of analytic methods. Much less attention has traditionally been paid to the development of methods of casting and forging or to the knowledge gained by Bronze Age metalworkers of the properties of different types of copper and its alloys. It has been shown above in the discussion of Eneolithic/Copper Age axes that metallography can provide important information to answer such questions and address the field of technological choice in early metallurgy. In this section the results of a metallographic examination of Early to Middle Bronze Age axes are reported, and an attempt is made to carry forward in time some of the points raised above in relation to Eneolithic/Copper Age metallurgy. Technological change during the early phases of the Bronze Age and the state of knowledge involved in the production of weapons or implements are examined in a long-term perspective, drawing on the microstructural evidence of Early Bronze Age Saxon, Salez and Neyruz type flanged axes, followed by those of Langquaid type axes and younger – mostly – Middle Bronze Age palstaves. The implications of the microstructural findings will be discussed in terms of the perception and manipulation of the properties of different types or alloys of copper and the role of local metalworking traditions in the transition to tin bronze. Since this development is often seen as straightforward ‘progress’, in the last section of this chapter the metallographic data is used to deconstruct some of the most common misconceptions on the superiority of tin bronze. Material properties did not simply evolve towards the ‘better’, and we should not employ such notions in simplistic explanations of technological change.

7.1 Bronze Age Axes: Chronology, Distribution and Data of this Study

In 1904 A. Lissauer first defined the Saxon type as a distinct group of (Early) Bronze Age flanged axes. They take their name from their suspected place of origin in the German part of the Únětice culture area, namely Saxony, where great numbers of such axes were known early on from large hoard finds such as Carsdorf and Bennewitz (fig. 7.1; Billig 1958). Axes of this type show a more or less heavily curved blade, narrow sides and a straight, outwardly domed or triangular neck. Hence, there is great formal variation, and beyond Saxony, or even the wider area of the Únětice culture, related forms are found across a broad area of central Europe and adjacent parts of the Carpathian Basin (fig. 7.2). Formal variation and their wide distribution subsequently gave rise to ever more sophisticated classificatory schemes, and Saxon axes or related forms are known by different type names in the different parts of their distribution area (see, for example, the relevant volumes in the PBF-series: Mayer 1977, 6, 76–84; Kibbert 1980, 16–19, 157–171; Říhovský 1992, 82–90; Pászthory/Mayer 1998, 10, 29–32). In south-western Germany and eastern Switzerland, for example, Salez type axes (see chapter 7.3), whose distribution covers both sides of Lake Constance (Abels 1972, 4–10; Krause 1988, 214–236; Bill 1997), may be seen as the westernmost subgroup of the Saxon type (e. g. Hafner 1995, 141–146).

While such forms are generally held to be Early Bronze Age, there is an ongoing discussion on their earliest appearance within that period and the time of their most widespread use (e. g. Kibbert 1980, 163–164; Mayer 1977, 79–83; Pászthory/Mayer 1998, 10, 31–32). Most recently, K. Rassmann (2005, 470–478) in his discussion of Únětice hoards containing such axes suggested that the Saxon type made an early appearance after c. 2200 cal BC, his metallurgical horizon II, but were most common in his younger horizons III (after c. 2000 cal BC) and IV (after c. 1900/1800 cal BC; see however Kienlin 2008a, 280–291 on problems with this approach to dating via composition). Similar problems concern the end of their use, since there is no agreement how to distinguish on typological grounds ‘proper’ Saxon type axes from younger palstaves of Middle Bronze Age date. This is because (younger) Saxon axes may also have a slight indication of a stop ridge (e. g. Novotná 1970, 33–44; Říhovský 1992, 104–107).

Saxon type axes and related forms such as Salez consist of the sulphidic fahlore copper widely used in Early Bronze

Fig. 7.1: Saxon type axes from the hoard of Bennewitz, Sachsen-Anhalt (after Hänsel/Hänsel 1997, 108).

Age central Europe. In addition, some are alloyed with tin (Kienlin 2008a, 121–186). Since this innovation is thought a somewhat later development, accordingly it has been suggested that at least the tin-alloyed axes should be dated to the second half of the Early Bronze Age (EBA A2). From this perspective axes without tin may represent a somewhat earlier stage of Early Bronze Age metallurgy, corresponding roughly to Early Bronze Age A1, while other scholars suggest a later, that is Early Bronze Age A2, date for both the majority of copper axes and for those consisting of tin bronze (cf. Abels 1972, 9–10; Krause 1988, 223–224; Hafner 1995, 96–98, 141–146; Bartelheim 1998, 47–50; Rassmann 2005, 471–478). It is certainly true that the widespread use of high-tin bronze is a feature of the second half of the Early Bronze Age (EBA A2). But there is a lot of variation in early tin contents, and such innovation does not occur instantaneous nor does it affect a larger area in a linear pattern. The position taken here is that composition is a poor guide to chronology, and the use of copper and bronze in Early Bronze Age weapons or implements provides a good example of such a transitional period: Metallographic analyses show that particular sorts of fahlore copper and tin bronze provided equal alternatives. Hence, access to 'competitive' fahlore copper probably had an effect on the acceptance of tin alloying and may regionally have contributed to a delayed adoption of this innovation. The early use of tin bronze, therefore, requires a differentiated approach, examining the effects this innovation had on metalworking in different regional contexts (see below).

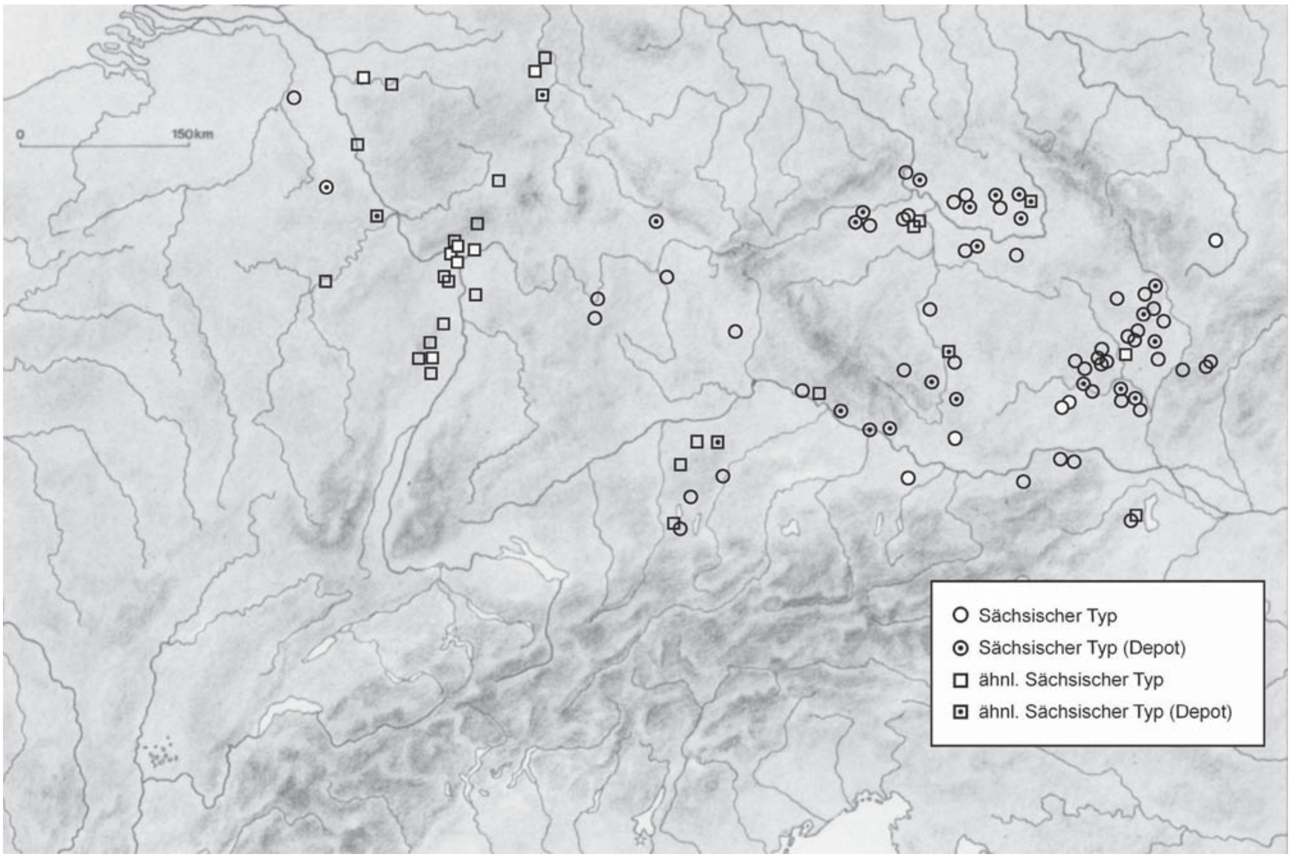


Fig. 7.2: The distribution of Saxon type axes and related forms in southern and western central Europe.

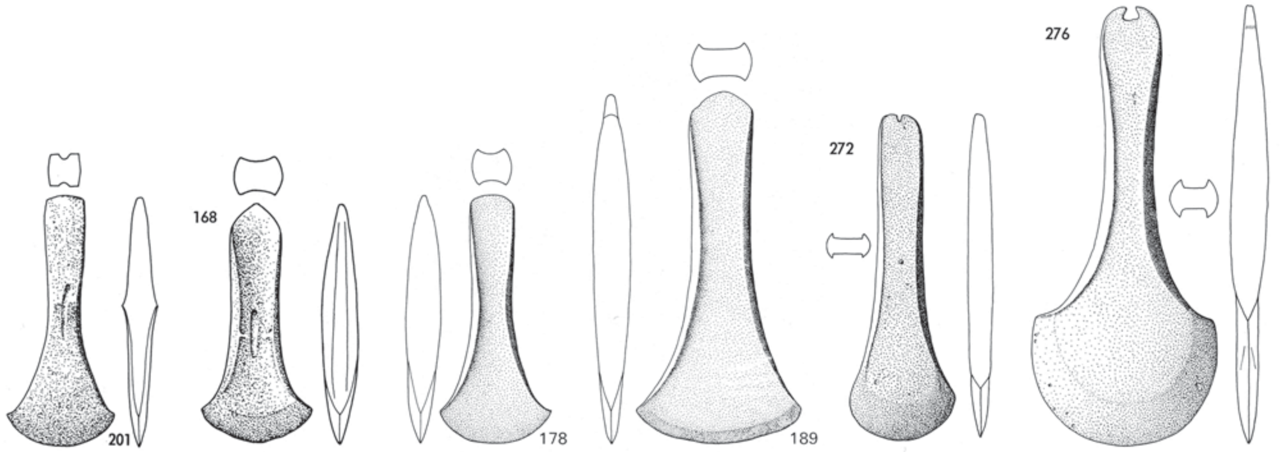


Fig. 7.3: Types of Bronze Age horizon 1 (EBA) flanged axes examined in this study (from left to right: Saxon [Novotná 1970, 36 no. 201, tab. 10.201, 33 no. 168, tab. 9.168; Říhovský 1992, 84 no. 178, tab. 14.178, 86 no. 189, tab. 14.189), Langquaid I (Mayer 1977, 92 no. 272, tab. 19.272) and Langquaid II (Mayer 1977, 92 no. 276, tab. 19.276).

For the present study a total of 62 Bronze Age axes was examined. The majority of them may be classified as Saxon type axes in the broadest sense. In the catalogue these axes are grouped together on purely formal grounds and appear under the heading of 'BA horizon 1 (EBA)' (fig. 7.3; see appendix II). For the reasons discussed above it is not intended to imply a more precise date (i. e. Early Bronze Age A1 or A2) for individual pieces or particular forms and features. There are both copper axes in this group and axes made of tin bronze. Both may contain fahlore specific trace elements such as arsenic, antimony, silver or nickel in highly variable amounts. The effect such compositional differences and the introduction of tin alloying had on the axes' manufacture and properties will be examined below by combining the present data to a previously published corpus of metallographic data of Saxon type axes (Kienlin 2008a, 157–186).

Some of the axes sampled for the present study come from the Únětice culture area of eastern Germany with a number of stray finds and some axes recovered from hoards such as the one piece sampled from the well-known Carsdorf hoard (sample no. 34). A larger number of samples, however, is available from the north-western part of the Carpathian Basin, from Slovakia and the Czech Republic (Moravia). There is some variation in details of size and shape, and in the PBF-volumes by M. Novotná (1970) and J. Říhovský (1992) these axes are labelled 'Randleistenbeile mit flachem Nacken und bogenförmiger Schneide' (sample nos. 51 and 54) or 'Randleistenbeile mit spitzem Nacken' (sample nos. 69 and 114), basically paraphrasing earlier definitions of the Saxon type (cf. Novotná 1970, 33); or they appear under absurd headings such as 'Gruppe III, Typ 3c, Variante Aab' (e. g. sample no. 127) or 'Gruppe IV, Typ 5c, Variante Dab' (e. g. sample no. 124) in an attempt to replace well-established terminology by a more 'logical' system (Říhovský 1992, 3, 76–77). Among these axes too there is a number of stray finds. There are also pieces from hoards such as the ones from Dobročkovice (fig. 7.4; sample nos. 131–135, 158, 162–163), and some axes were recovered from graves (e. g. sample nos. 51 and 114).

The dates given for these axes by Novotná (1970, 33–34, 36–37) and Říhovský (1992, 82–83, 88–90, 107, 117–118) are roughly equivalent to the lifespan of such forms outlined above in central European terms, i. e. Early Bronze Age A1 and A2. Some of the better dated grave and hoard finds point towards late Únětice and related culture groups, with an occasional occurrence of Saxon type axes into the transition to the Middle Bronze Age (e. g. Novotná 1970, 37). Correspondingly, there are problems to distinguish some typologically 'young' Saxon axes with a stop ridge from palstaves traditionally thought to belong to the Middle Bronze Age and grouped into our Bronze Age horizon 2 (see below). There is in fact continuity from flanged axes of the Saxon type to various different younger (Middle Bronze Age) axe forms (see also Mayer 1977, 79–84, 91–96).

In our 'BA horizon 1'-group, some pieces were included that do not perfectly match the Saxon type, but by their form and context are broadly contemporaneous, i. e. (late) Early Bronze Age. Among them there are the flanged axe from the hoard of Dunajská Streda already mentioned (sample no. 54; Novotná 1970, 36), an 'axe-shaped ingot' of type Niederosterwitz (sample no. 75; Mayer 1977, 66–71; for discussion see below) and the fragment of an axe (blade) of unclear type from an Early Bronze Age settlement site at Křižanovice (sample no. 146; Říhovský 1992, 107).

The axes from the Plavnice hoard were included in this group 1 (fig. 7.5; sample nos. 171–174; Stein 1979, 101 no. 232) because they illustrate one possible line of development from Saxon type axes towards such of types Langquaid I and II with drawn in, narrow sides and a strongly curved cutting edge (Abels 1972, 34–41; Mayer 1977, 91–96; see also the Langquaid type axes with sample nos. 167–169 from Hradce; Stein 1979, 100 no. 228). At the same time they highlight the problems resulting from smooth transitions in prehistoric reality vis-à-vis our

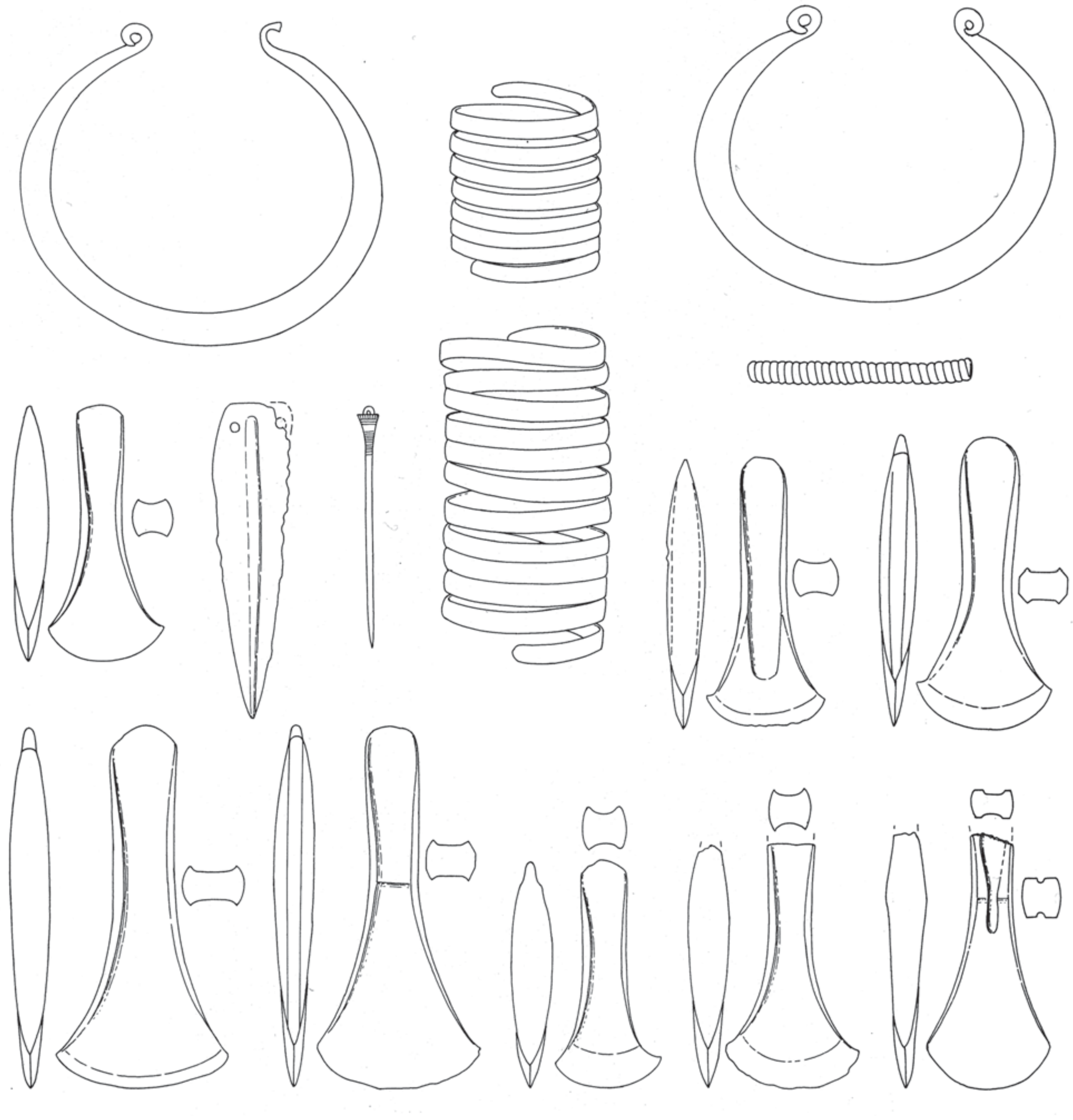


Fig. 7.4: Finds from the Early Bronze Age hoard from Dobročkovice, Moravia (after Říhovský 1992, tab. 84B).

attempts to distinguish ideal archaeological types arranged in chronological sequence. For Kibbert (1980, 170) in Plavnice there is the 'developmental sequence' from (older) Saxon type axes, variants Halle and Carsdorf or type Langquaid I to (younger) 'almost' variant Wilhering of type Langquaid II. Mayer (1977, 95–96), on the other hand, does not recognise any Langquaid I axes in the Plavnice find; but his variant Plavnice of type Langquaid II in other hoards such as Heimhilgen in Bavaria (and by other scholars) is equated with 'form Heimhilgen' = type Langquaid I (compare Mayer 1977, 96 and Pászthory/ Mayer 1998, 46–47 to Ruckdeschel 1978, 45; cf. Kienlin 2008a, 217–219).

Clearly, the transitions between our 'types' or 'variants' are far from clear-cut, and the chronological implications

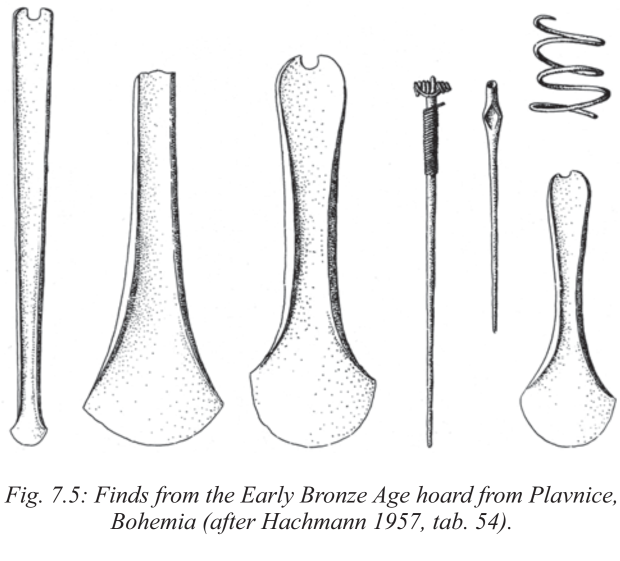


Fig. 7.5: Finds from the Early Bronze Age hoard from Plavnice, Bohemia (after Hachmann 1957, tab. 54).

of related notions of 'old-fashioned' versus 'progressive' forms are entirely unclear. Different 'types' were in circulation at the same time, or at least they were deposited together in hoards such as Plavnice. Below it will be asked what variability of shape and form meant in terms of production, properties or function(s) and meaning(s) assigned to the axes upon exchange and use. For the time being, we may refer back to P. Reinecke (1924), who used Langquaid type axes – amongst other finds from the eponymous hoard of Langquaid in Lower Bavaria (fig. 7.6) – to define his Early Bronze Age phase A2, so that their date roughly corresponds to (a majority of?) Saxon type axes (see above). Subdivided into numerous variants, which in part can be distinguished according to region, Langquaid axes have a wide distribution in southern and south-western Germany, Switzerland and Austria (Abels 1972, 34–41; Mayer 1977, 91–96). Unlike the Saxon type axes, however, which are only sometimes alloyed and with highly variable tin contents, the Langquaid ones are regularly alloyed with about 10 % or more tin. This may point to a somewhat later date of Langquaid axes during Early Bronze Age A2, for they were also made of a new type of copper (*ostalpines Kupfer*), that shows comparatively low impurity contents (Krause 1998, 172; 2003, 199). However, there may also be an element of preferential access to tin and technological or aesthetic choices involved in such high tin contents. In any case Langquaid type axes provide the opportunity to examine the effects of this innovation on production and properties of another large group of Early Bronze Age axes in greater detail. Again it is drawn on previously published data as well in order to increase numbers and strengthen the statistical relevance of our findings (Kienlin 2008a, 221–241).

Bearing in mind the problems mentioned with modern categorisation and its chronological implications, it is expected that there is some chronological overlap between some of our BA horizon 1 axes discussed above and our second group of Bronze Age axes tentatively listed under the heading of 'BA horizon 2 (late EBA to MBA/LBA palstaves etc.)' (fig. 7.7; see appendix II). On formal grounds in this group there are flanged axes and palstaves that may have started in the late Early Bronze Age, but – with some modifications – remained in use somewhat longer than the above forms throughout the Middle Bronze Age and in part reach the Late Bronze Age (fig. 7.8; Novotná 1970, 38–53; Mayer 1977, 112–124; Říhovský 1992, 108–147). Hence, although some of these axes clearly belong into the later phases of the Early Bronze Age or the transition to the Middle Bronze Age (e. g. sample nos. 115–117 from graves in Jelšovce; Bátora 2000), this group as a whole provides an opportunity to follow up the development of methods of casting and forging, as well as the use made of tin bronze into the later phases of the Bronze Age. In total there are 17 axes in this group (see appendix II). Among them there is a large number of axes of unknown origin. From the collection they are kept in it is expected that they originate from the north-western part of the Carpathian Basin, i. e. from Slovakia. The axes consist of tin bronze. Again, there is some variation in details of size and shape. By M. Novotná (1970) two of these palstaves are still listed under the heading of 'Randleistenbeile mit flachem Nacken und bogenförmiger Schneide' (see above; sample nos. 57 and 60). The remaining ones represent different types of palstaves such as Novotná's (1970) 'Absatzbeile mit spitzer Rast' (e. g. sample no. 61) or her 'Absatzbeile mit gerader Rast' (sample no. 50) depending on the shape of their stop ridge. Artefacts that can be confidently placed as the youngest pieces in this group are a median-winged axe (sample no. 67), and an end-winged axe (sample no. 66), which date to the Late Bronze Age period.

7.2 The Casting and Working of Bronze Age Axes: Outline of the Metallographic Evidence

Among the microstructures examined there is meaningful patterning. Differences in working can be observed that correspond to changes in composition and transformations of local metalworking traditions through time. However, first it is useful to outline the production parameters and microstructural features that are found throughout practically all Bronze Age axes and therefore have universal validity for this group of implements irrespective of type, composition or date.

With only few exceptions (see below) the vast majority of Bronze Age axes examined show a fully recrystallised microstructure (figs. 7.9 M8 and 7.10 M8; see also the corresponding tables in appendix II). In all these samples there is evidence of twinning with twin bands visible in many or most grains throughout the whole sample area (figs. 7.9 M9 and 7.10 M9). A heat treatment was applied strong enough to erase the original casting grains and allow the growth of new equi-axed grains with straight grain boundaries. In some axes there still is strong residual coring, though more commonly some degree of homogenisation was achieved, and only weak residual coring or no coring at all remains (figs. 7.9 M6 and 7.10 M6). Similarly, in some of the axes – depending on composition – there are still various intermetallic phases (in unalloyed axes; see below) or the δ-phase in tin bronzes (i. e. the α/δ-eutectoid; Schumann 1991, 645), but these as well were partly homogenised in most of the axes (figs. 7.9 M4/5 and 7.10 M4/M5).

Under prehistoric conditions, or more generally speaking upon casting in a pre-industrial context, coring and the formation of additional phases in the copper matrix will take place even at rather low contents of trace or alloying elements (Northover 1989; 1996; Buchwald/Leisner 1990; Scott 1991; Lechtman 1996; Kienlin 2008a). Equilibrium is never reached, and after solidification there is a dendritic as-cast microstructure with irregularly formed, cored casting grains interspersed with additional phases in which trace elements such as arsenic or antimony or the alloying element tin are concentrated (figs. 7.11 and 7.12). Unlike the sulphide and oxide inclusions present in many axes as well (figs. 7.9 M2/3 and 7.10 M2/M3), which point to the use of sulphidic ores and casting under fairly oxidising conditions (see below), intermetallic phases upon heating

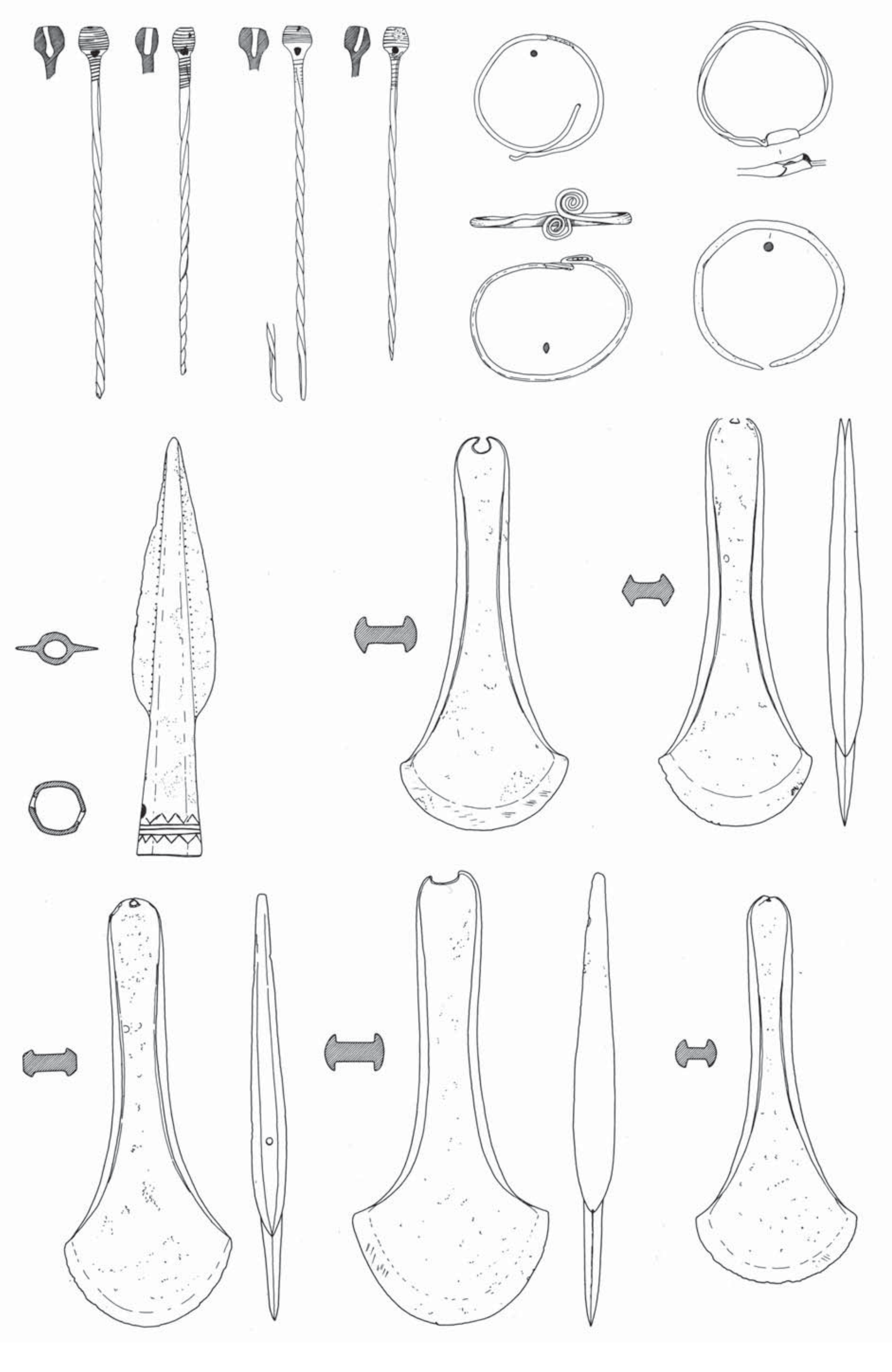


Fig. 7.6: Finds from the eponymous Early Bronze Age hoard of Langquaid, Lower Bavaria (after Stein 1979, tabs. 32 and 33).

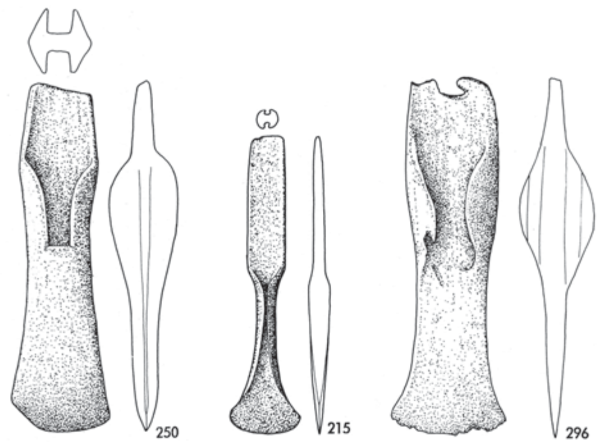


Fig. 7.7: Types of Bronze Age horizon 2 (late EBA to MBA/LBA) axes examined in this study (from left to right: palstaves [Novotná 1970, 42 no. 250, tab. 13.250, Novotná 1970, 39 no. 215, tab. 11.215] and median-winged axe [Novotná 1970, 46 no. 296, tab. 16.296]).

may dissolve into the copper matrix. However, since the original amount of such phases is unknown, and their dissolution is a local process, their presence or absence is a poor guide to the intensity of heating (see Kienlin 2008a, appendix I). For coring to be removed, on the other hand, large-scale movement of impurities throughout the copper matrix is required. This involves prolonged heating at high temperatures (Budd 1991b; Schumann 1991), and homogenisation of coring, therefore, provides a hint towards more intense heating. However, unlike modern practice it is unlikely that this was carried out as a separate production step or that homogenisation was deliberately aimed for to improve mechanical properties. Rather, heating took place to restore deformability (in modern terms: due to grain growth and stress relief), and the presence or absence of coring simply points to some variation in this process. This variation, however, was negligible with regard to the intended outcome of the process: In all axes of this group recrystallisation is complete, i. e. deformability was restored, and in no case is there evidence of continued grain growth due to excessive heating in terms of temperatures applied or duration of exposure to the forge (figs. 7.11 and 7.12).

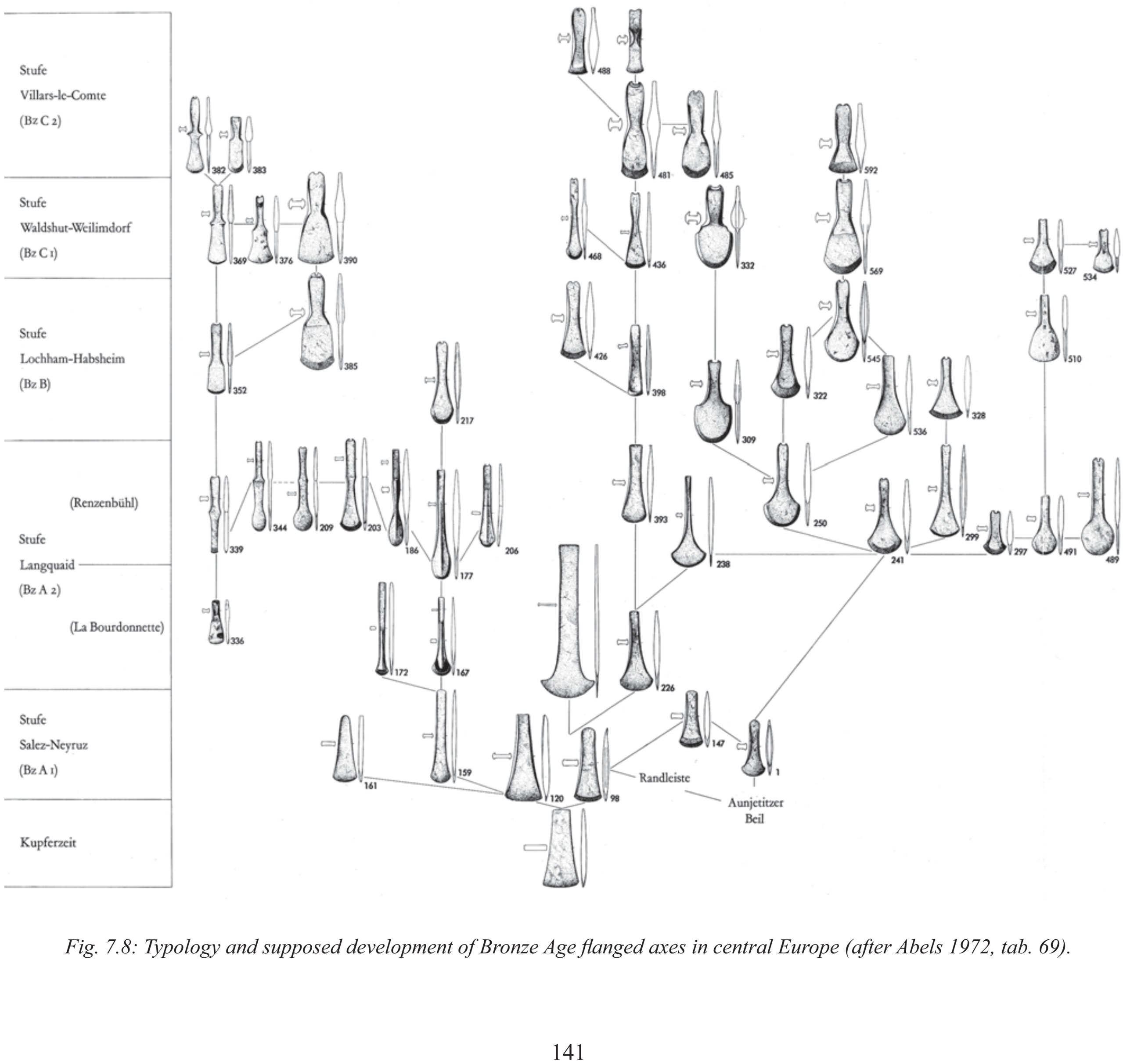


Fig. 7.8: Typology and supposed development of Bronze Age flanged axes in central Europe (after Abels 1972, tab. 69).

Sample no.	Porosity, phases and inhomogeneities						Production steps						Final cold work					Total working		
	M1	***M2***	***M3***	***M4***	***M5***	***M6***	***M7***	***M8***	***M9***	***M10***	***M11***	***M12***	***M13***	***M14***	***M15***	***M16***	***M17***	***M18***	***M19***	***M20***
Bronze Age horizon 1 (EBA Saxon type flanged axes etc.)																				
1	(x)	(x)	(x)	0	0	0	0	xx	xx	xx	xx	xx	0	(x)	xx	20-30%	(x)	-	-	-
2	x	x	x	x	(x)	0	0	xx	x	xx	xx	x	x	x	xx	35-40%	0	-	-	-
7	0	(x)	x	x	0	(x)	0	xx	x	xx	(x)	x	xx	xx	xx	45-50%	x	xx	xx	70-80%
8	0	x	0	0	0	(x)	0	xx	xx	xx	x	x	x	x	xx	40-45%	0	-	x	>50%
9	x	0	xx	0	x	(x)	0	xx	x	xx	x	x	x	x	xx	35-40%	0	x	x	~50%
11	x	x	x	0	0	0	0	xx	xx	xx	xx	xx	0	x	xx	20-30%	x	x	-	-
17	x	x	x	x	0	0	0	xx	x	xx	xx	(xx)	x	x	xx	35-40%	0	x	-	-
18	x	0	(x)	0	(x)	0	0	xx	x	xx	xx	(xx)	x	x	xx	35-40%	0	-	-	-
20	0	0	x	0	0	xx	0	xx	xx	xx	0	(x)	x	x	xx	35-40%	0	x	x	>50%
21	0	0	x	0	0	x	0	xx	xx	xx	x	x	xx	xx	xx	45-50%	0	x	x	>>50%
22	xx	(x)	x	x	0	x	0	xx	x	xx	(x)	(x)	x	x	xx	35-40%	xx	x	-	>50%
26	0	0	x	0	0	0	0	xx	x	xx	xx	(xx)	xx	xx	xx	45-50%	0	x	-	>>50%
27	0	0	x	(x)	0	(x)	0	xx	x	xx	x	x	x	x	xx	35-40%	0	-	-	-
28	0	0	(x)	(x)	0	(x)	0	xx	x	xx	x	x	xx	xx	(xx)	45-50%	(x)	-	-	-
34	0	0	x	0	0	(x)	0	xx	x	xx	x	(xx)	xx	xx	xx	45-50%	0	xx	x	70-80%
51	x	0	x	0	0	(x)	0	xx	x	xx	x	x	x	x	xx	40-45%	x	xx	(x)	70-80%
54	x	(x)	xx	0	xx	xx	x	0	0	x	0	-	0	-	(xx)	~20%	0	0	0	~20%
69	x	xx	(x)	0	0	0	0	xx	xx	xx	xx	(xx)	xx	xx	(xx)	45-50%	x	x	-	>>50%
75	xx	x	(xx)	0	0	(xx)	x	0	0	0	0	-	0	-	0	0%	0	0	0	0%
114	(x)	(x)	(x)	0	0	0	0	xx	x	xx	xx	(xx)	x	x	xx	40-45%	0	-	-	>>50%
119	(x)	(x)	(x)	0	0	(x)	0	xx	xx	xx	x	x	x	x	xx	40-45%	0	x	-	>50%
124	x	xx	(x)	(x)	0	0	0	xx	xx	xx	xx	(xx)	(x)	x	xx	30-35%	0	x	-	>50%
125	x	x	0	0	0	0	0	xx	x	x	xx	xx	0	0	0	0%?	0	-	-	<<50%
126	(x)	0	xx	0	x	0	0	xx	x	xx	xx	(xx)	x	x	xx	35-40%	0	x	-	>50%
127	x	x	x	0	0	(x)	0	xx	x	xx	x	x	(xx)	xx	xx	~45%	0	x	-	>>50%
131	0	0	(x)	0	0	0	0	xx	x	xx	xx	xx	(x)	x	xx	~40%	0	-	-	>50%
132	0	x	0	0	0	0	0	xx	x	xx	xx	xx	x	x	xx	40-45%	0	-	-	-
133	x	(xx)	(x)	0	0	x	0	xx	xx	xx	x	x	(x)	x	-	30-35%	0	x	-	-
135	(x)	xx	(x)	0	0	(x)	0	xx	xx	xx	x	x	x	x	xx	40-45%	0	(x)	-	>50%
145	0	0	0	0	0	x	0	xx	x	xx	x	x	(x)	x	xx	30-35%	0	-	(x)	-
146	x	xx	x	0	0	0	0	xx	x	x	xx	xx	0	0	0	0%	0	(x)	-	<<50%
151	(x)	(xx)	0	0	0	0	0	xx	x	xx	xx	(xx)	xx	xx	xx	>50%	0	xx	-	70-80%
152	(x)	(xx)	(x)	0	0	(x)	0	xx	x	xx	x	x	(xx)	xx	xx	~45%	x	xx	(x)	70-80%

158	(x)	(x)	0	0	0	(xx)	0	xx	x	xx	(x)	(x)	x	x	xx	40-45%	0	-	x	>>50%
159	x	(x)	(x)	0	0	x	0	xx	x	xx	x	(x)	xx	xx	-	45-50%	0	x	x	>>50%
162	x	xx	(x)	(x)	0	x	0	xx	x	xx	x	(x)	0	x	-	10-15%	0	(x)	x	<<50%
163	x	x	(x)	(x)	0	(xx)	0	xx	x	xx	(x)	(x)	(x)	x	xx	30-35%	x	(x)	(x)	<50%
166	x	(x)	xx	xx	0	x	x	x(?)	x(?)	xx(?)	0	(x)	0	-	xx(?)	~20%(?)	0	x	-	~30%(?)
167	x	(x)	xx	0	(xx)	(xx)	0	xx	xx	xx	(x)	(x)	0	x	xx	20-30%	0	(x)	0	<50%
168	0	0	xx	0	0	(x)	0	xx	xx	xx	x	x	0	(x)	xx	20-30%	0	(x)	-	<50%
169	(xx)	(x)	xx	0	0	0	0	xx	xx	xx	xx	xx	(x)	x	xx	~30%	0	(x)	-	<50%
171	0	(x)	xx	0	0	(x)	0	xx	x	xx	x	x	xx	xx	xx	>50%	0	xx	x	70-80%
172	0	0	(x)	0	0	(x)	0	xx	x	xx	x	x	(xx)	xx	xx	~45%	0	-	x	>>50%
173	0	(x)	x	0	0	x	0	xx	x	xx	x	x	x	x	xx	40-45%	(x)	-	x	>>50%
174	0	0	x	0	0	0	0	xx	x	xx	xx	(xx)	x	x	xx	35-40%	0	xx	-	70-80%

Fig. 7.9: Microstructural features of the Bronze Age horizon 1 axes examined for this study (EBA Saxon type flanged axes etc.). M1: porosity (0 = none/hardly any; x = occasionally; xx = frequent) – M2: oxide inclusions (0 = none/hardly any; x = occasionally; xx = frequent) – M3: sulphide inclusions (0 = none/hardly any; x = occasionally; xx = frequent) – M4: intermetallic phases (0 = none/hardly any; x = occasionally; xx = frequent) – M5: α/δ-eutectoid in tin bronze (0 = none/hardly any; x = occasionally; xx = frequent) – M6: coring in copper matrix (0 = none/hardly any; x = weak residual coring; xx = heavily cored) – M7: casting grains (0 = none; x = present) – M8: recrystallisation (0 = none; x = partial; xx = complete) – M9: annealing twins (0 = none; x = frequent; xx = in most/all grains of sample area) – M10: production steps after casting (0 = none; x = as-cast, cold worked, or: cold worked, annealed, or: hot worked; xx = cold worked, annealed, cold worked, or: hot worked, final cold work) – M11: homogenisation (0 = none; x = partial; xx = complete) – M12: intensity of annealing (0 = equi-axed grains; x: equi-axed grains, partly homogenised; xx: equi-axed grains, homogenised) – M13: deformation of grains (0 = none; x = moderate; xx = heavily deformed) – M14: deformation of twins (0 = none; x = moderate; xx = heavily deformed) – M15: strain lines (0 = none; x = one system; xx = duplex slip) – M16: strength of final cold work (% reduction in thickness, close to the cutting edge/tip of the sample) – M17: wear traces (0 = none; x = additional deformation at the cutting edge due to moderate use; xx = tip of the sample heavily deformed due to heavy use) – M18: deformation/breakage of porosity/other phases (0 = none; x = moderate; xx = heavily deformed) – M19: deformation of coring (0 = none; x = moderate; xx = heavily deformed) – M20: estimated total reduction in thickness (% reduction in thickness, close to the cutting edge/tip of the sample).

Sample no.	Porosity, phases and inhomogeneities						Production steps						Final cold work					Total working		
	M1	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**	**M11**	**M12**	**M13**	**M14**	**M15**	**M16**	**M17**	**M18**	**M19**	**M20**
Bronze Age horizon 2 (late EBA to MBA/LBA palstaves etc.)																				
50	0	(x)	(xx)	0	0	(x)	0	xx	xx	xx	(xx)	(xx)	0	0	xx	20-30%	0	0	-	<50%
53	0	(x)	(xx)	0	0	0	0	xx	xx	xx	xx	xx	0	x	xx	20-30%	-	xx	-	>>50%
57	0	(x)	xx	0	x	xx	0	xx	x	xx	0	0	(x)	(x)	xx	~30%	0	(x)	0	<50%
60	(x)	0	xx	0	0	(x)	0	xx	x	xx	x	x	x	x	xx	35-40%	0	x	(x)	>50%
61	0	0	xx	0	x	x	0	xx	x	xx	x	x	x	x	xx	35-40%	0	(xx)	x	>>50%
63	x	(x)	(xx)	0	0	0	0	xx	xx	xx	xx	xx	x	x	xx	~40%	0	x	-	>50%
65	0	(x)	xx	0	x	x	0	xx	x	xx	x	x	x	x	xx	40-45%	0	(xx)	x	>>50%
66	0	(x)	xx	0	xx	0	0	xx	xx	xx	xx	xx	x	x	xx	40-45%	(x)	(xx)	-	>>50%
67	x	(x)	xx	0	0	xx	0	xx	xx	xx	0	0	x	x	xx	40-45%	0	(xx)	(xx)	>>50%
68	(x)	0	xx	0	(x)	(xx)	0	xx	xx	xx	(x)	(x)	0	(x)	(xx)	~20%	0	x	x	>50%
70	0	0	(xx)	0	0	xx	0	xx	xx	xx	0	0	0	x	(x)	~20%	0	(x)	(x)	<50%
71	x	(x)	(xx)	0	xx	xx	0	xx	x	xx	0	0	0	(x)	(xx)	~20%	0	0	0	<<50%
73	x	(x)	(xx)	0	0	0	0	xx	xx	x?	xx	xx	0	(x)?	0	0%?	0	0	-	<<50%
115	0	(xx)	x	0	0	0	0	xx	x	xx	xx	xx	xx	xx	xx	45-50%	0	xx	-	>>50%
116	0	(x)	(xx)	0	0	(x)	0	xx	x	xx	(xx)	(xx)	(xx)	xx	xx	~45%	-	xx	-	>>50%
117	x	0	(xx)	0	(xx)	0	0	xx	x	xx	xx	xx	x	x	xx	40-45%	-	(xx)	-	>>50%
150	x	0	xx	0	x	xx	x	0	0	x	0	-	0	-	xx	20-30%	0	0	(x)	20-30%

Fig. 7.10: Microstructural features of the Bronze Age horizon 2 axes examined for this study (late EBA to MBA/LBA palstaves etc.). M1: porosity (0 = none/hardly any; x = occasionally; xx = frequent) – M2: oxide inclusions (0 = none/hardly any; x = occasionally; xx = frequent) – M3: sulphide inclusions (0 = none/hardly any; x = occasionally; xx = frequent) – M4: intermetallic phases (0 = none/hardly any; x = occasionally; xx = frequent) – M5: α/δ-eutectoid in tin bronze (0 = none/hardly any; x = occasionally; xx = frequent) – M6: coring in copper matrix (0 = none/hardly any; x = weak residual coring; xx = heavily cored) – M7: casting grains (0 = none; x = present) – M8: recrystallisation (0 = none; x = partial; xx = complete) – M9: annealing twins (0 = none; x = frequent; xx = in most/all grains of sample area) – M10: production steps after casting (0 = none; x = as-cast, cold worked, or: cold worked, annealed, or: hot worked; xx = cold worked, annealed, cold worked, or: hot worked, final cold work) – M11: homogenisation (0 = none; x = partial; xx = complete) – M12: intensity of annealing (0 = equi-axed grains; x: equi-axed grains, partly homogenised; xx: equi-axed grains, homogenised) – M13: deformation of grains (0 = none; x = moderate; xx = heavily deformed) – M14: deformation of twins (0 = none; x = moderate; xx = heavily deformed) – M15: strain lines (0 = none; x = one system; xx = duplex slip) – M16: strength of final cold work (% reduction in thickness, close to the cutting edge/tip of the sample) – M17: wear traces (0 = none; x = additional deformation at the cutting edge due to moderate use; xx = tip of the sample heavily deformed due to heavy use) – M18: deformation/breakage of porosity/other phases (0 = none; x = moderate; xx = heavily deformed) – M19: deformation of coring (0 = none; x = moderate; xx = heavily deformed) – M20: estimated total reduction in thickness (% reduction in thickness, close to the cutting edge/tip of the sample).

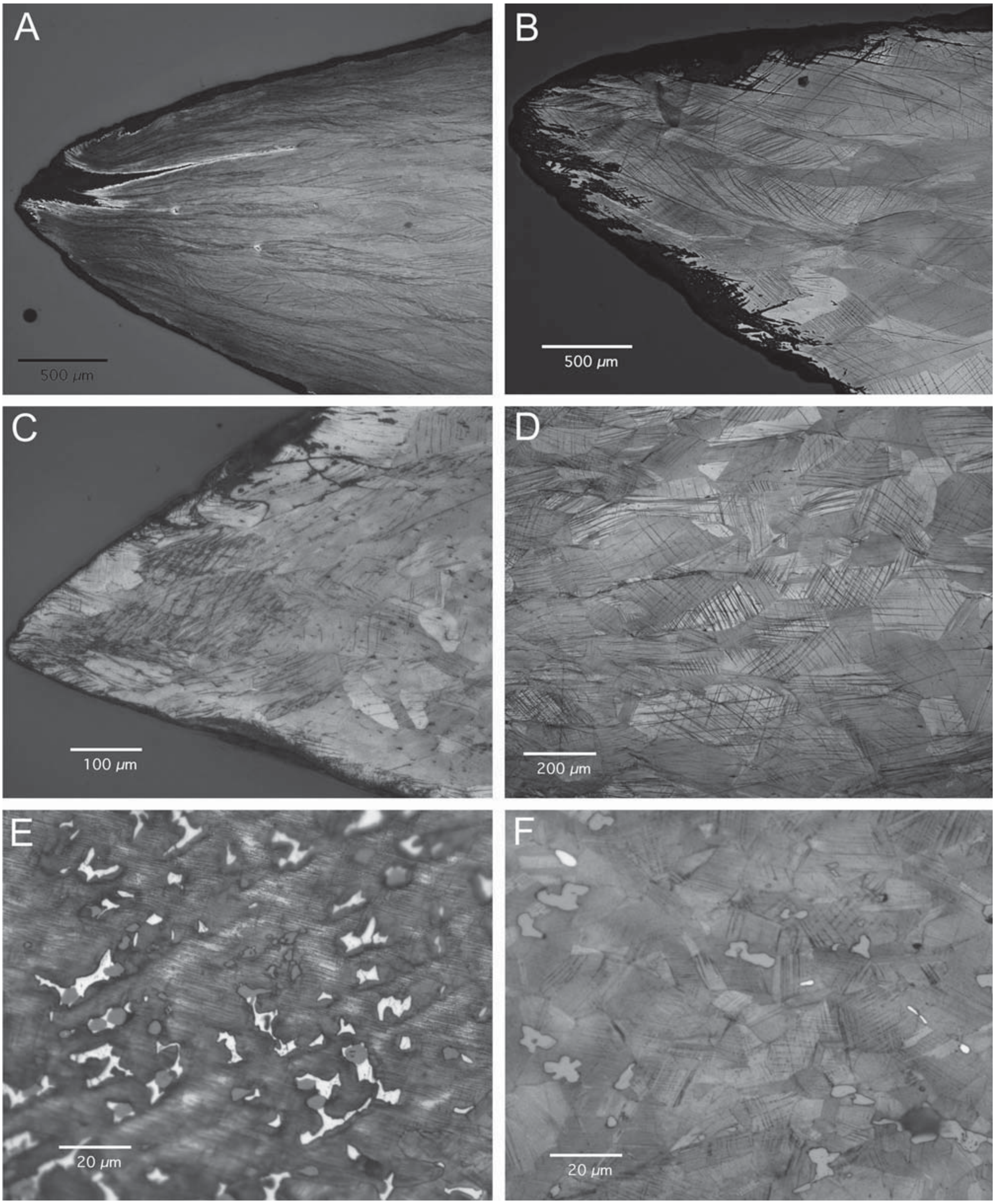


Fig. 7.11: Characteristic microstructures of the Bronze Age horizon 1 axes examined for this study (A: sample no. 114 [note the heavily deformed grains in consequence of a strong final cold work]; B: sample no. 132 [note the heavily deformed grains in consequence of a strong final cold work]; C: sample no. 163; D: sample no. 119 [note the strain lines indicative of weaker final cold work in the backward core of this sample]; E: sample no. 54 [note the interdendritic patterning of the α/δ-eutectoid in this high-tin bronze]; F: sample no. 167 [note the copper sulphide inclusions that are hardly deformed in the backward core of this sample]).

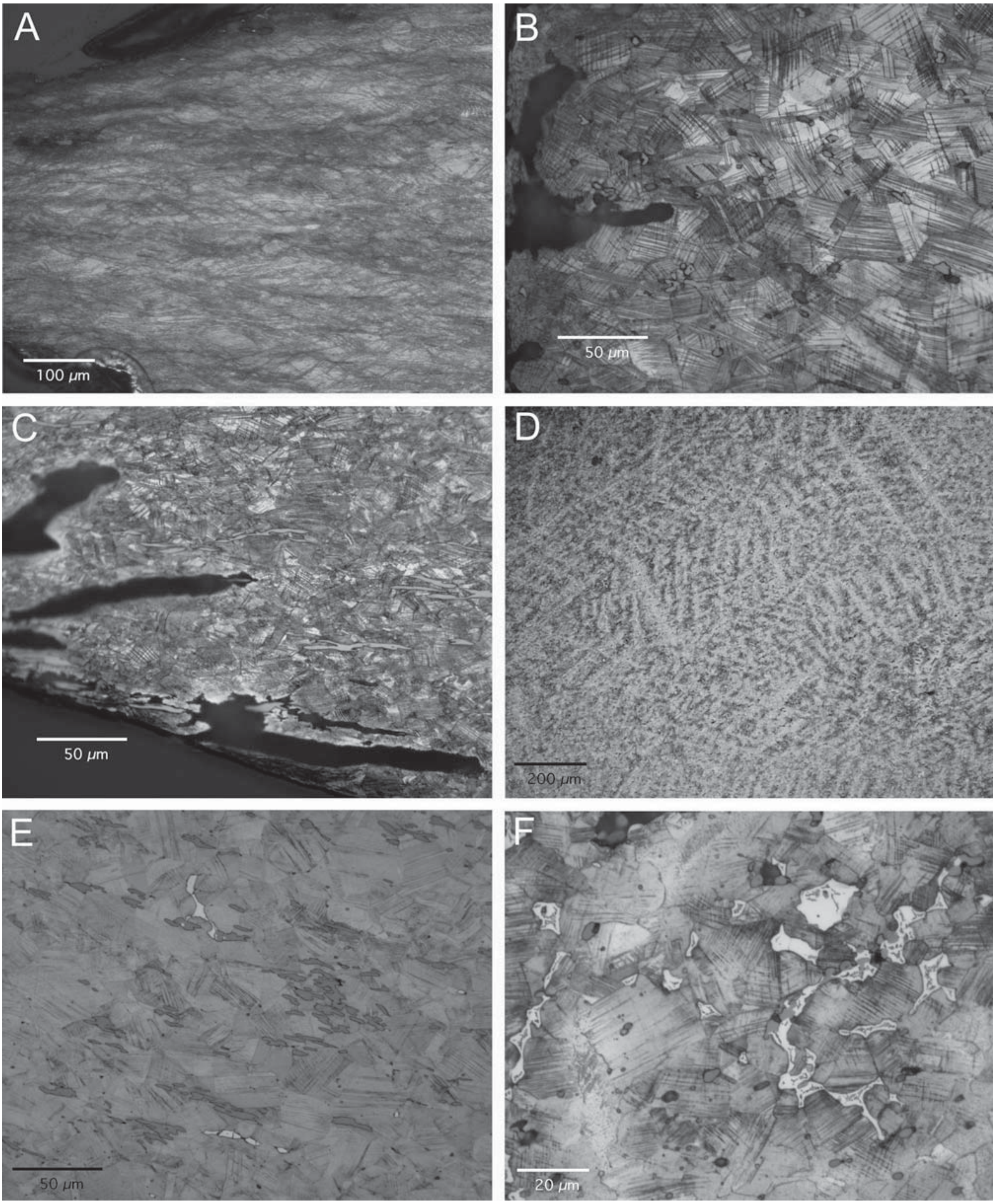


Fig. 7.12: Characteristic microstructures of the Bronze Age horizon 2 axes examined for this study (A: sample no. 115 [note the heavily deformed grains in consequence of a strong final cold work]; B: sample no. 50 [note the strain lines indicative of weaker final cold work]; C: sample no. 61 [note the heavily deformed sulphide inclusions indicative of a high total reduction in thickness]; D: sample no. 71 [note the dendritic patterning retained by the inhomogeneities]; E: sample no. 66 [note the somewhat less heavily deformed sulphide inclusions in the backward core of this sample]; F: sample no. 71 [note the frequent α/δ-eutectoid in this high-tin bronze]).

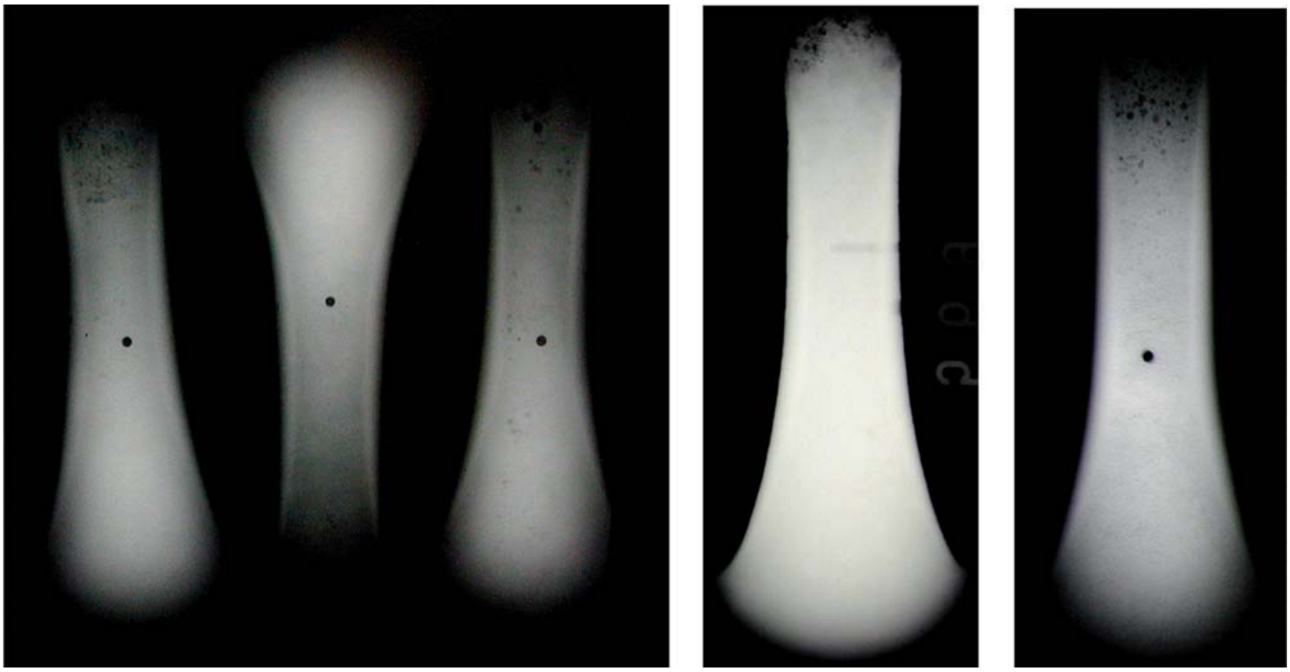


Fig. 7.13: X-ray images of Salez type axes showing increased porosity in the neck of the axes due to gas evolution and shrinkage upon solidification in an upright standing closed mould (after Kienlin 2008a, 132 fig. 38).

Porosity, the presence of oxide inclusions and residual coring provide evidence of casting as the first step of production (figs. 7.9 and 7.10; M1, M2 and M6 respectively). Oxygen pick-up occurred while the copper was molten down as well as upon pouring into the mould. From the amount of pores and oxides present in some of the axes it is clear, that by modern standards control over casting atmosphere was generally poor, and gas evolution during solidification was high. Admittedly, the number of utterly spoilt casts is unknown, but from the microstructure of the axes surviving, i. e. worked and finished after their removal from the mould, one gets the impression that neither oxide inclusions nor porosity posed serious problems for further working and subsequent use. Typically, there is the same kind of mixed copper/copper-arsenic etc. oxides present that was described above in Eneolithic/Copper Age horizon 2 flat axes (see chapter 4.3). Upon working these oxide inclusions broke up or became plastically deformed (Northover 1989, 112), but they did not affect workability in the way the ($Cu+Cu_2O$)-eutectic did in older Eneolithic/Copper Age horizon 1 axes (see chapter 4.2).

Unlike the Eneolithic/Copper Age that may have seen the occasional use of mixed oxidic and sulphidic ores, but typically drew on oxidic copper ore deposits, the copper used during the Bronze Age was derived from sulphidic ores on a regular basis. For the fahlore copper, which was used for some of the Early Bronze Age axe types, this can be demonstrated by its characteristic trace element signature (Krause 2003). But throughout all types examined, including younger ones such as the Middle Bronze Age palstaves in our 'BA horizon 2 (late EBA to MBA/LBA)', there is direct evidence of the use of sulphidic copper ores in form of sulphide inclusions in their microstructures (figs. 7.9 M3 and 7.10 M3). If subsequent working does not deform them these copper sulphides sometimes retain their dendritic shape (figs. 7.11 and 7.12). This shows that the copper including all 'impurities' was molten, and copper sulphide was the first phase to solidify from a homogeneous one-phase melt at around 1.100 °C (Lesniak 1991; Kienlin 2008a, 133–136). We will return to this finding below in our discussion of the effect of tin on casting temperatures (see chapter 7.5.1).

Further information on the casting process may come from the secondary dendrite armspacing in as-cast microstructures, which differs according to moulding material and solidification rates (Ottaway 1994, 122–123, fig. 17). Unfortunately, since there are hardly any as-cast microstructures left this approach is not viable for the axes under consideration. Apart from stone or clay moulds, of which there is little evidence in the Early Bronze Age, the widespread use of sand moulds in prehistory has been suggested (for references see chapter 3.4). Although this casting method leaves little traces in the archaeological record, and there is no direct evidence of its use, it is thought likely that it was applied in the production of Early Bronze Age axes as well (Kienlin 2008a, 255–262). Based on a metallographic examination and secondary dendrite armspacing, for contemporaneous Ösenringe of the Early Bronze Age (which exhibit a higher number of as-cast microstructures), casting in sand moulds is thought likely by M. Junk (2003, 62–127, 170). Generally speaking, as shown above, closed (two-piece) moulds were in use already in the Eneolithic/Copper Age (see chapters 3.4 and 4.4). 'Simple' shape is not an argument in favour of open moulds, and in the production of Early Bronze Age axes, some of them still similar to earlier flat axes with their flanges not very pronounced, casting certainly took place in closed moulds as well. Direct evidence comes from the increased porosity

in the neck of some axes shown by X-rays (fig. 7.13), which proves that casting took place in a closed, upright standing mould. More circumstantial evidence comes from metallographic samples with a limited overall reduction in thickness, that cannot be related to casting in an open mould (figs. 7.9 M20 and 7.10 M20). In addition, the even distribution of oxides in the metallographic sections does not support the assumption of open mould casting, which would have caused the oxide inclusions to cluster along the upper uncovered surface (see above in chapters 3.4 and 4.4 for a similar point in relation to Eneolithic/Copper Age axes previously supposed to have been cast in open moulds; Kienlin/Bischoff/Opielka 2006; Kienlin 2008b; Kienlin/Pernicka 2009).

As mentioned above, few axes were left in the as-cast condition with traces of little or no subsequent working (figs. 7.9 and 7.10; M7, M8 and M10 respectively; sample nos. 54, 75, 150 and 166). Among them there are two samples with unusually high tin or trace element contents (fig. 7.14; sample no. 54: 13.44 % Sn; sample no. 166: 16.6 % TE). Strain lines indicate that some working took place, but it is likely that the high amount of the hard and brittle α/δ-eutectoid or intermetallic phases (for the latter see discussion in chapter 7.3.1) hampered working, and/or hardness was felt to be sufficient anyway. With sample no. 75 there is an 'axe-shaped ingot' of type Niederosterwitz. Its porous as-cast microstructure clearly sets this piece apart from the proper axes, but this group of objects nonetheless remains enigmatic (Mayer 1977, 66–71): From the near-shape casting applied in the production of the axes examined (see above) and the limited deformation involved in the forging of their flanges (Kienlin 2008a, 144–155, 170–186) it is quite clear that no rough blank was involved in their production. So the Niederosterwitz type 'axe-shaped ingot' certainly were not a preform for the production of flanged axes. Their overall number is limited – compared, for example, to the hundreds of *Ösenringe* and *Spangenbarren* known – so their interpretation as widely used ingots remains problematic as well. Beyond this group of objects there are a number of theoretical problems with the notion of Early Bronze Age 'ingots' and directional trade in copper (see chapter 8).

Typically, after their removal from the mould the axes were worked to their final shape and surface finish. Theoretically, this might have involved reheating and forging above recrystallisation temperature (hot working). But near-shape casting and the predominance of pieces that were heavily cold worked in the final step are a strong argument in favour of a cyclical approach to forging with an initial cold work to compensate for any defects that remained after casting, followed by annealing and repeated cold hammering to improve mechanical properties (see figs. 4.19 and 5.3). The first step removed casting seams or any surface defects that remained from the casting process. The blade was given its final outline, and the cutting edge was sharpened. Subsequent annealing resulted in the fully recrystallised microstructure of the axes already mentioned above. Annealing twins point to the deformation that was achieved prior to this heat treatment (figs. 7.9 M9 and 7.10 M9). There is evidence that annealing took place rather early in the smithing process (Junk 2003, 170; Kienlin 2008a, 173), which may show that in some cases a stronger deformation was required than easily was achieved in one go. Annealing then would in fact have been carried out to restore deformability for further working and shaping. However, bearing in mind the casting method applied (see above) and quite a number of axes with a limited total reduction in thickness (figs. 7.9 M20 and 7.10 M20), more often another consideration seems to have been involved: After initial working with shape and surface finish in mind, the deformation that was achieved was probably unevenly distributed all over an axe's body and blade. Annealing would then have been carried out to 'reset' mechanical properties for final cold work in order to add to the strength and durability of the cutting edge in a defined way. For this is exactly what the strength of final cold work typically seen in our axes implies (figs. 7.9 M16, 7.10 M16, 7.11 and 7.12): There was an interest in the hardness of the axes, and some broadly defined cold work of medium strength was carried out to improve their durability. Excessively heavy deformation, on the other hand, such as may result from the 'mixing up' of the different steps of shaping etc. and final cold work without intermediate annealing, was avoided. In terms of hardness there is little advantage from such a strong deformation (see below), and it may eventually cause brittleness.

With this approach to forging the Bronze Age axes clearly stand in a tradition of our Eneolithic/Copper Age horizon 2 flat axes discussed above (see chapters 4.3 and 4.6). A multi-stage process of working with interposed annealing is the norm. Initially, this may have been achieved by use of relatively simple implements such as 'hammer' stones or pebbles and stone 'anvils' (e. g. Leuzinger 1997, 51–52; 2000, 142–142; 2002, 59; cf. Hirsch/Graf 1999, 78–79), and it is only from somewhat later in the Bronze Age that a specialised set of tools such as hammers, anvils etc. for the working of copper and gold are known (Wyss 1971; Hundt 1975; Coghlan 1975; Ehrenberg 1981; Tylecote 1987; Mohen 1990; Ottaway 1994; Bertemes/Schmotz/Thiele 2000; Armbruster 2000; 2006; Kuijpers 2008, 40–41, 97–106). Forging can be seen only partially as a shaping operation. An interest in their mechanical properties determined the production method for the axes, and the good knowledge of materials and procedure already developed in the Late Neolithic or Eneolithic/Copper Age period is confirmed for the Bronze Age as well. Owing to the use of new (fahlore) copper types and the emergence of tin bronze, most Bronze Age axes achieved a relatively high hardness (figs. 7.14 and 7.15). For example, most Saxon type axes have values in the 130 HV to 230 HV range with occasional readings up to about 260 HV. Upon use, they would have exhibited a significantly increased durability compared with most of the older, typically low arsenical, copper axes. This is a result of the use of new copper types from sulphide ore deposits and the availability of tin as an alloying element. However, the interaction between composition and manufacturing techniques was

Sample no.	*HV pt1*	*HV pt3*	*Cu*	*S*	*Sn*	*Pb*	*As*	*Sb*	*Ag*	*Ni*	*Co*	*Fe*	*Bi*	*Sum TE*
Bronze Age horizon 1 (EBA Saxon type flanged axes etc.)														
1	168.2	111.4	93.6	-	4.8	0.1	0.3	-	0.7	0.1	0.3	-	-	1.5
2	188.1	120.1	93.5	-	2.7	-	0.4	0.9	1.3	0.8	-	-	-	3.4
7	173.4	151.4	94.5	-	0.6	-	-	1.5	0.8	2	0.2	0.1	-	4.6
8	148.9	101.2	95.7	-	0.3	-	0.2	0.9	1	1.2	0.2	-	0.2	3.7
9	217.5	183.4	89.2	0.3	9.7	-	-	-	0.1	0.3	-	0.2	-	0.6
11	154.9	88	94	0.1	4.4	-	0.3	0.2	0.3	0.1	0.2	-	0.1	1.2
17	219.9	141.5	89.6	0.1	2.4	0.3	0.1	3.4	1.2	1.8	0.4	0.5	-	7.7
18	216	191.7	94.1	-	4.8	-	0.2	0.2	0.4	-	-	0.1	-	0.9
20	162.3	118.9	86.8	0.2	0.5	0.3	2.9	3.5	2.8	1.2	-	0.1	-	10.8
21	193	140.7	94.1	0.1	1.7	-	0.2	1	0.7	1.7	-	0.1	0.2	3.9
22	186.9	76.3	93.5	-	0.8	0.2	0.3	2.1	1	1.5	0.2	-	-	5.3
26	190.5	149.7	95	-	1.9	-	0.3	0.8	1.2	0.1	0.2	0.1	-	2.7
27	134	124.5	96.6	-	-	-	0.2	0.7	1.4	0.8	-	-	-	3.1
28	172.4	76.6	97	-	-	0.4	0.3	1	0.9	-	-	0.5	-	3.1
34	208.8	178.9	96.3	-	3	-	0.1	0.1	0.4	-	-	0.1	-	0.7
51	229.9	211.7	92.3	-	6.9	-	-	-	0.7	-	-	-	-	0.7
54	198	172.4	82.6	0.6	13.4	-	0.7	-	-	1.8	-	0.7	-	3.2
69	161.4	117.1	96	-	-	-	0.7	1.5	1.3	0.3	-	0.1	-	3.9
75	52.2	52	97.5	0.8	0.2	-	-	0.4	-	0.8	0.1	-	-	1.3
114	166.2	125.1	95.9	-	-	-	1	1.1	1.6	-	-	0.4	-	4.1
119	185.7	149.7	94.3	-	3.3	-	-	0.8	0.5	0.8	-	-	-	2.1
124	126.4	105.1	97	0.2	-	-	-	0.7	1.5	0.5	-	-	-	2.7
125	135.5	85.4	92.5	-	-	-	1.2	1.9	1.4	2.4	0.4	-	-	7.3
126	220.5	174.5	88	0.2	11.2	-	-	-	-	-	-	0.4	-	0.4
127	182.7	159.5	94.3	-	0.4	-	0.8	2.2	2.1	-	-	0.1	-	5.2
131	200.7	154	95.9	-	2.3	-	-	-	1.2	-	-	0.4	-	1.6
132	152.2	136.2	97.6	-	0.3	-	-	0.8	0.9	-	0.2	-	-	1.9
133	127.1	115.3	96.3	-	-	-	0.6	1.3	1.2	0.5	0.2	-	-	3.8
135	156.7	131.2	97	-	0.7	-	-	0.7	1.1	-	0.3	-	-	2.1
145	136.2	109.2	97.8	-	-	-	-	0.5	1.2	-	-	0.1	-	1.8
146	64.3	57.3	94.1	-	-	-	2.4	1.7	1.5	-	-	-	-	5.6
151	168.5	130.5	95.8	-	-	-	1.4	0.5	1.5	0.3	0.3	-	-	4
152	163.3	119.5	97.5	-	-	-	0.9	-	1	0.3	0.2	-	-	2.4
158	152.2	120.7	95.9	-	-	-	0.8	0.8	1.4	0.4	-	0.4	-	3.8
159	166.2	119.5	97.8	-	0.5	-	-	0.4	1.2	-	-	-	-	1.6
162	98.9	103.6	95	-	0.3	-	1	0.9	2.4	0.5	-	-	-	4.8
163	152.2	125.1	95.3	-	0.6	-	0.8	1.4	1.3	0.3	0.3	-	-	4.1

166	148	140.7	81.3	1.7	-	-	1.5	7.4	4.1	3.1	0.3	0.2	-	16.6
167	211.7	164.3	85	0.5	10.9	-	2.3	-	0.5	0.7	-	-	-	3.5
168	207.4	149.7	89.5	0.6	8.9	-	-	-	0.2	0.6	-	-	-	0.8
169	256.3	211.7	85	0.2	11	-	0.9	0.4	0.6	1.4	-	0.1	-	3.4
171	256.3	208.8	87.7	-	11.3	-	-	0.4	0.2	-	-	0.2	-	0.8
172	243.4	194.2	87.5	-	10	-	0.7	0.4	1	0.3	-	-	-	2.4
173	234.1	202	90.8	-	7.8	-	-	0.7	0.6	-	-	-	-	1.3
174	208.6	169.3	90.5	-	7.8	-	-	0.5	0.8	-	-	0.2	-	1.5

Fig. 7.14: Hardness and composition of the Bronze Age horizon 1 axes examined for this study (EBA Saxon type flanged axes etc.; Vickers microhardness HV0.1 at the tip of the sample [pt. 1 = cutting edge] and at the back of the sample [pt. 3 = core]; EDX analyses, weight-%, rounded to one decimal).

Sample no.	***HV pt1***	***HV pt3***	***Cu***	***S***	***Sn***	***Pb***	***As***	***Sb***	***Ag***	***Ni***	***Co***	***Fe***	***Bi***	***Sum TE***
Bronze Age, horizon 2 (late EBA to MBA/LBA palstaves etc.)														
50	137.7	123.2	89	0.2	9	-	-	0.6	-	0.7	-	0.3	-	1.6
53	229.9	214.5	86	-	13	-	-	-	0.3	0.3	-	0.2	-	0.8
57	181.1	177.7	89.3	0.6	8.2	-	-	0.5	-	1	-	0.2	-	1.7
60	217.5	165.2	90.9	0.6	6.9	-	-	0.7	0.3	0.5	-	-	-	1.5
61	226.7	183.4	87.4	0.3	10.3	-	0.6	0.4	-	0.8	-	0.2	-	2
63	207.4	182.2	89.3	-	8.5	-	0.6	0.5	0.6	-	0.7	-	-	2.4
65	228.3	206	89.5	0.6	8.4	-	0.5	-	-	0.4	-	0.5	-	1.4
66	233.2	190.5	85.8	0.5	11.2	-	0.7	0.9	-	0.7	-	-	-	2.3
67	233.2	181.1	91.1	0.4	6.7	-	0.3	0.8	0.3	0.4	-	-	-	1.8
68	185.7	175.6	87.2	0.6	10	-	0.7	0.4	-	0.9	-	-	-	2
70	120.7	111.9	95.9	0.2	2.1	-	1	-	-	0.4	-	0.2	-	1.6
71	177.7	161.4	84.8	-	13.8	-	0.3	0.9	-	-	-	0.1	-	1.3
73	114.7	99.4	86.6	0.3	11.2	-	0.4	0.4	-	0.6	0.2	0.2	-	1.8
115	225.1	202	93.1	0.3	5.6	-	0.5	-	-	0.5	-	-	-	1
116	228.3	211.7	88.7	-	9.2	-	0.4	0.8	0.4	-	-	0.3	-	1.9
117	206	163.3	85.8	0.1	13.2	-	-	0.5	0.3	-	-	-	-	0.8
150	189.3	176.6	91.7	0.3	7	-	-	-	-	0.7	-	-	-	0.7

Fig. 7.15: Hardness and composition of the Bronze Age horizon 2 axes examined for this study (late EBA to MBA/LBA palstaves etc.; Vickers microhardness HV0.1 at the tip of the sample [pt. 1 = cutting edge] and at the back of the sample [pt. 3 = core]; EDX analyses, weight-%, rounded to one decimal).

not uniform, and tin bronze was by no means superior in every context, particularly so when compared to Early Bronze Age fahlore copper instead of (older) arsenical copper. There are technological choices involved in the use of different types of copper or the adoption of tin bronze. Regional differences in the use made of the available copper types can be observed, as well as different reactions to the introduction of tin alloying during the Early Bronze Age. These will be the main focus of the following sections.

Finally, self-evident as the Bronze Age procedure outlined may appear in modern eyes – forging for shape and hardness in separate production steps –, we should recall some of the earlier findings discussed above. In our Eneolithic/Copper Age horizon 1 both shaft-hole axes and flat axes were hot worked as a shaping operation (see chapters 3 and 4.2). There was no step of final cold work carried out. Forging/shaping and mechanical properties were conceptually set apart, and the latter were possibly linked to the handling of the casting process (in modern terms: the amount and type of the eutectic present after casting), if hardness was thought accessible to manipulation at all. Hence cold working for hardness must not be taken for granted. It is an element of a specific tradition that consistently denied alternative technological choices. Metallurgy of the Únětice culture, to which Saxon type axes are traditionally affiliated, is often seen as progressive in terms of the use of tin bronze for elaborate cast objects (e. g. Müller 2002b; Krause 2003). The Saxon axes as well testify to a high standard of casting technique, successful in terms of the requirements in the production of weapons or tools. However, the skill involved certainly was not that much different from the earlier Eneolithic/Copper Age production of comparable implements, or from contemporaneous Early Bronze Age groups of the north alpine region of central Europe and the Carpathian Basin. Furthermore, the emphasis on forging for hardness in the production of Saxon type axes and the specific use of tin bronze made in this tradition (see chapter 7.4.1) show that we should not try to characterise the metallurgy of a group, culture or territory such as 'Únětice' by a narrow reference to specific innovations (= tin bronze) put to particular 'innovative' uses (= the casting of ornaments and prestigious halberds and solid-hilted daggers).

7.3 From Copper to Bronze I: Salez Axes of the North Alpine Region

Unlike the question of copper and tin origins that has been extensively investigated with the help of analytic methods, but often with inconclusive results, rarely an attempt has been made to understand the introduction of tin bronze in terms of the knowledge of the properties of different types of copper and its alloys, and the choices taken on this basis by prehistoric metalworkers. In the north alpine region of central Europe this is a gradual process in the course of which tin bronze took the place of pure copper, arsenical copper or fahlore metal in the production of various types of artefacts. However, rather than focus on mere problems of access and availability of copper and tin we have to turn to the domain of cognitive aspects and technological choice for a better understanding of the spread of innovations such as the use of tin bronze – or their (temporary) refusal.

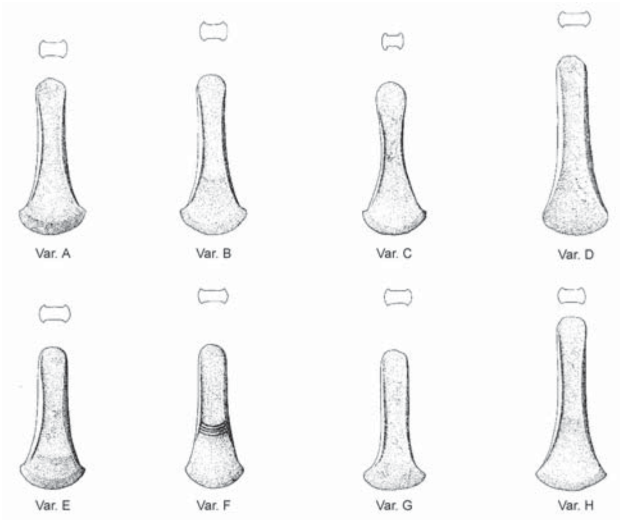


Fig. 7.16: The different variants of Salez type axes (after Kienlin 2008a, 14 fig. 2; Abels 1972).

A first example of such processes is provided by the Early Bronze Age flanged axes of the so-called Salez type (Kienlin/Bischoff/Opielka 2006; Kienlin 2008a, 121–155). Named after a large hoard from Sennwald-Salez in the Swiss canton of St. Gallen (Bill 1977; 1985; 1997), the axes of this type with numerous variants have a curved cutting edge, narrow outline and an arched butt (fig. 7.16). Salez axes are closely related to the flanged axes of the Saxon type discussed above, and they may be seen as a south-western extension or subgroup of that form. Their distribution covers a region on both sides of Lake Constance between the alpine valley of the Rhine in the south and the Danube in the north. Salez axes represent the earliest flanged axes in this area, and can be dated roughly to the first half of the Early Bronze Age between c. 2200–1900/1800 cal BC (Abels 1972, 4–10; Krause 1988, 214–236; 1996; 1998; Hafner 1995, 141–146).

Although they belong to the Early Bronze Age, Salez axes were not alloyed with tin. They represent a period in which alloying with tin was only gradually introduced, for instance for axes of the neighbouring Saxon (see above) and Neyruz types (Strahm 1994; Pernicka 1998). However, in part they contain high amounts of trace elements or impurities such as antimony, arsenic, nickel and silver, that mark the transition from the use of oxide ores to sulphide ores of the so-called fahlore (*Fahlerz*) type (Krause 1988, 219–232; 2003, 189–199; Kienlin 2008a, 121–125). The question arises what effects this type of copper had on the production and properties of Salez axes. In a previous study referred to in this chapter it was possible to sample 33 axes of the Salez type and related forms (Kienlin 2008a). In a very general sense, these reach considerably higher hardness values than in the earlier Eneolithic/Copper Age axes discussed above

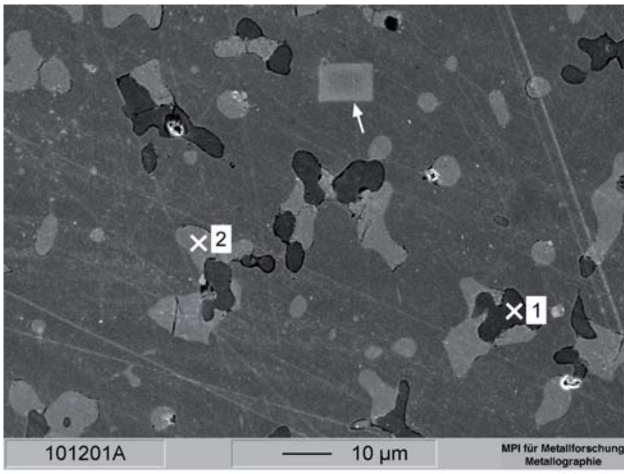
Sample no. 101201	*Cu*	*S*	*Sn*	*Pb*	*As*	*Sb*	*Ag*	*Ni*	*Co*	*Fe*
EDX, matrix (point)	88,29	0	0	0	2,51	4,7	1,44	2,64	0,42	0
EDX, matrix (point)	89,52	0	0	0	2,16	4,39	1,22	2,21	0,5	0
EDX, matrix (point)	88,19	0	0	0	2,64	4,64	1,49	2,81	0,23	0
EDX, matrix (mean)	88,67	0	0	0	2,44	4,58	1,38	2,55	0,38	0
EDX, larger sample area	78,99	1,34	0	0	3,61	9,42	1,23	4,7	0,73	0
EDX, dark grey phase [1]	74,64	20,73	0	3,36	0	0,36	0,3	0,41	0,2	0
EDX, light grey phase [2]	31,85	0	0	0,26	6,46	41,11	0,58	15,63	4,13	0
EDX, light grey phase [3]	32,99	0,04	0,27	4,6	4,84	37,04	0,26	21,35	2,52	0
WDX, light gr. phase [4]	41,38	4,39	0,2	0,52	3,89	31,01	0,85	18,19	2,61	0,02
WDX, light gr. phase [5]	36,23	0,02	0,19	0,72	4,89	36,79	0,47	21,51	2,66	0
WDX, dark gr. phase [6]	78,97	20,27	0	0,56	0,03	0,06	0,03	0,31	0,12	0,01
WDX, matrix	89,19	0	0,04	0,06	2,06	4,21	1,09	2,85	0,3	0
SAM II,3 2768	-	-	tr.	0,2	1,75	>>6	1,4	4,2	0	tr.

Fig. 7.17: Bulk composition and point analyses (copper sulphide [dark grey] and intermetallic phases [light grey]) of an axe from the hoard of Sennwald-Salez (weight-%); points 1 to 4 marked in fig. 7.18 (after Kienlin 2008a, 88 tab. 4).

in chapters 3 and 4. Prior to – or instead of – alloying with tin, the use of such fahlore metal is therefore likely to have brought about a clear increase in the durability and the attractiveness of tools or weapons over those made from previous copper sources. As such, however, Salez axes are notable for their variability in terms of working and properties, and they provide important insights into the transitional period to full-fledged Bronze Age metallurgy.

7.3.1 Working Fahlore Copper I: Sennwald-Salez and Hindelwangen

Seven axes examined from the eponymous hoard of Sennwald-Salez and some related specimens from the Hindelwangen hoard (Stein 1979, 30–31) deserve special attention as their trace element contents lie considerably above maximum solubility. For this reason there are significant differences between bulk composition and point analyses (fig. 7.17), that can be traced back to the existence of further phases in the copper matrix. Apart from copper sulphide these are intermetallic phases, in which arsenic and antimony, nickel and cobalt mutually replace each other in copper compounds (fig. 7.18; Lesniak 1991, 127–143; Lechtman 1998; Thornton/Rehren/Pigott 2009, 308). Even in unetched condition the ordering of the intermetallic phases between the arms of the initially solidified, copper-rich dendrites is visible. After etching, large, irregularly formed casting grains can be seen in the core area of all the samples (fig. 7.19, left). The dendritic structure shows that no stronger deformation affected this area. It is only close to the cutting edge and along the surface that there are smaller-grained zones with occasional annealing twins, suggesting superficial hammering and local recrystallisation. The frequent intermetallic phases, however, hindered the formation of straight grain boundaries and slowed down recrystallisation (Schumann 1991, 395–401; Bargel/Schulze 1988, 27–30). What made the copper of these axes special was therefore primarily the limited effect of attempted annealing. The axes remained difficult to work.



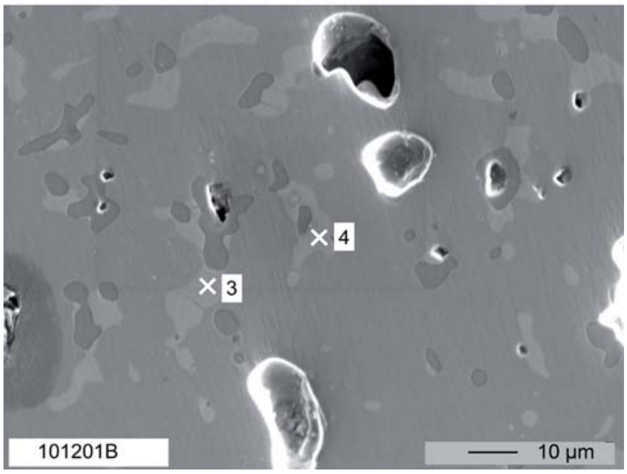


Fig. 7.18: Copper sulphide (dark grey) and intermetallic phases (light grey) in an axe from the hoard of Sennwald-Salez (for composition see fig. 7.17; marked with an arrow the 'area' of a typical point analysis of the copper matrix (after Kienlin 2008a, 87 fig. 30).

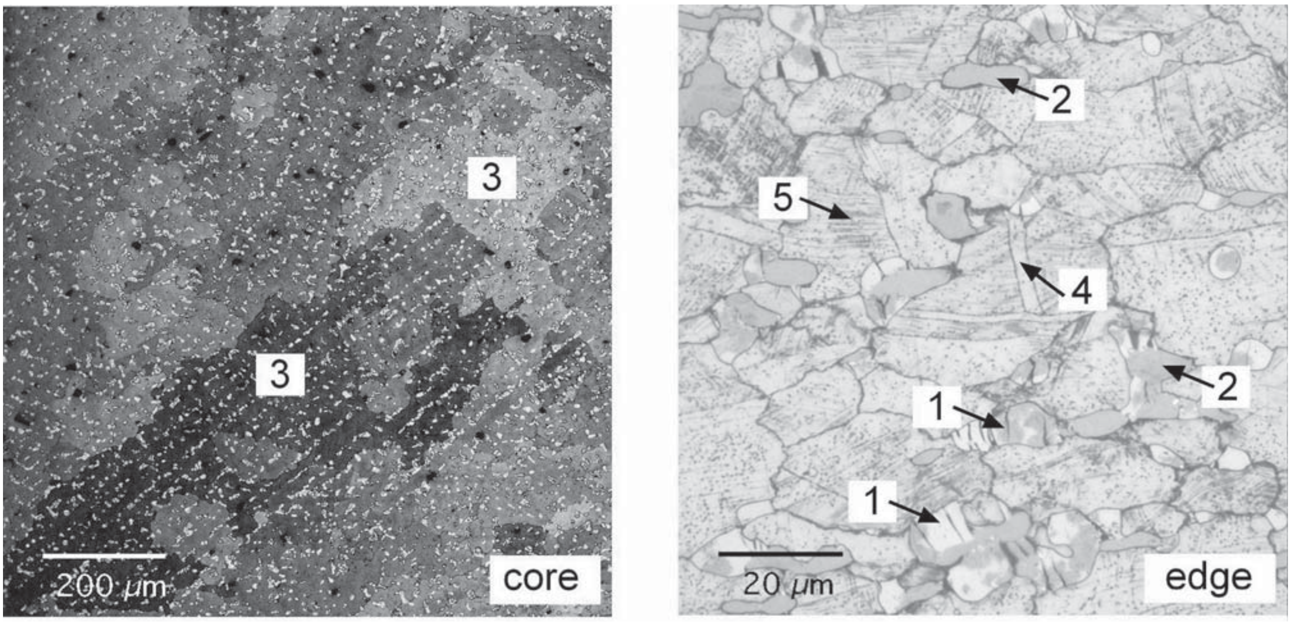


Fig. 7.19: Copper matrix, intermetallic phases (1) and copper sulphide (2) in an axe from the hoard of Sennwald-Salez. Left: Casting grains (3) and interdendritic patterning of intermetallic phases. Right: Recrystallised grains with annealing twins (4) near the cutting edge of the same axe; strain lines due to a rather weak cold work (5); as a result of deformation intermetallic phases are broken up (after Kienlin/Bischoff/Opielka 2006, 459 fig. 3).

As for the axes from Hindelwangen, their blades show no indication of final cold working and what little hammering took place prior to the attempted heat treatment is best understood as superficial working to improve the as-cast surface. In principle the same holds true for the axes from Sennwald-Salez, but their microstructure close to the surface shows occasional strain lines indicative of a final cold working of limited intensity (fig. 7.19, right). In terms of hardness the samples from Hindelwangen range from about 110 HV to 120 HV (fig. 7.20). A comparable hardness is encountered in the undeformed core of the samples from Sennwald-Salez. For a 10 % arsenical copper an as-cast hardness of 85 HV has been recorded (Lechtman 1996, 496), and it is obvious that the above values are considerably higher than expected from the matrix composition of the axes with 10 % to 12 % impurities (see also Northover 1989, 113–114 figs. 13.3, 13.4 and 13.5; Budd/Ottaway 1991, 140 figs. 4 and 5; Junk 2003, 156 fig. 7.26; Kienlin 2008a, 263–264 figs. 54 and 55). Even with microhardness tests it was not possible to determine the hardness of the copper matrix alone. Instead, the hardness values reflect the presence of a high ratio of hard intermetallic phases. These contribute to an extraordinarily high as-cast hardness, that – with only a mild forging – exceeds 170 HV for most of the Sennwald-Salez axes (fig. 7.20). Thus, these axes are also remarkable for their high as-cast hardness and the ease with which, upon cold working, very high hardness values could be obtained.

The frequent appearance of intermetallic phases is doubtlessly accompanied by brittleness. This led to the assumption that with axes of this kind, forging would hardly have been possible (Lesniak 1991, 241–246). However, samples taken from the flanges show a remarkable elongation of copper sulphides and reduced porosity due to hammering. As these features are restricted to the microstructure close to the surface, it is clear that the flanges were cast (Kienlin 2008a, 126–142). We can see a finishing operation, for example the removal of casting seams that ran along the outside of the flanges in the as-cast state. This finding, however, also testifies to the possibility of a high total reduction in thickness without cracking. It is clear that the raw material used *did* permit (cold) working. With full knowledge of the properties of this specific copper the effort of deformation was reduced and, therefore, extensive working of the blade did not occur. In the case of Hindelwangen there was no attempt to increase the already high as-cast hardness, whereas at Sennwald-Salez with comparatively little effort one produced axes whose mechanical properties may have rendered them desirable weapons or tools. Since both operated in the same broad tradition and similar levels of understanding the copper used can be assumed, it is tempting to interpret this in terms of different attitudes of the metalworkers towards the non-metalworking population, their 'consumers'.

7.3.2 Working Fahlore Copper II: Salez Axes with Lower Impurity Contents

On most Salez axes, which have less abundant intermetallic phases, more intense working in several stages is the rule. There is a clear tendency towards a higher total reduction in thickness and heavier cold hammering in the last step (fig. 7.21). Work hardening occurred, which ultimately necessitated annealing. Here, in contrast to Sennwald-Salez and Hindelwangen, the heat treatment actually led to a complete recrystallisation and facilitated further working. If a stronger deformation was necessary, this could – in the

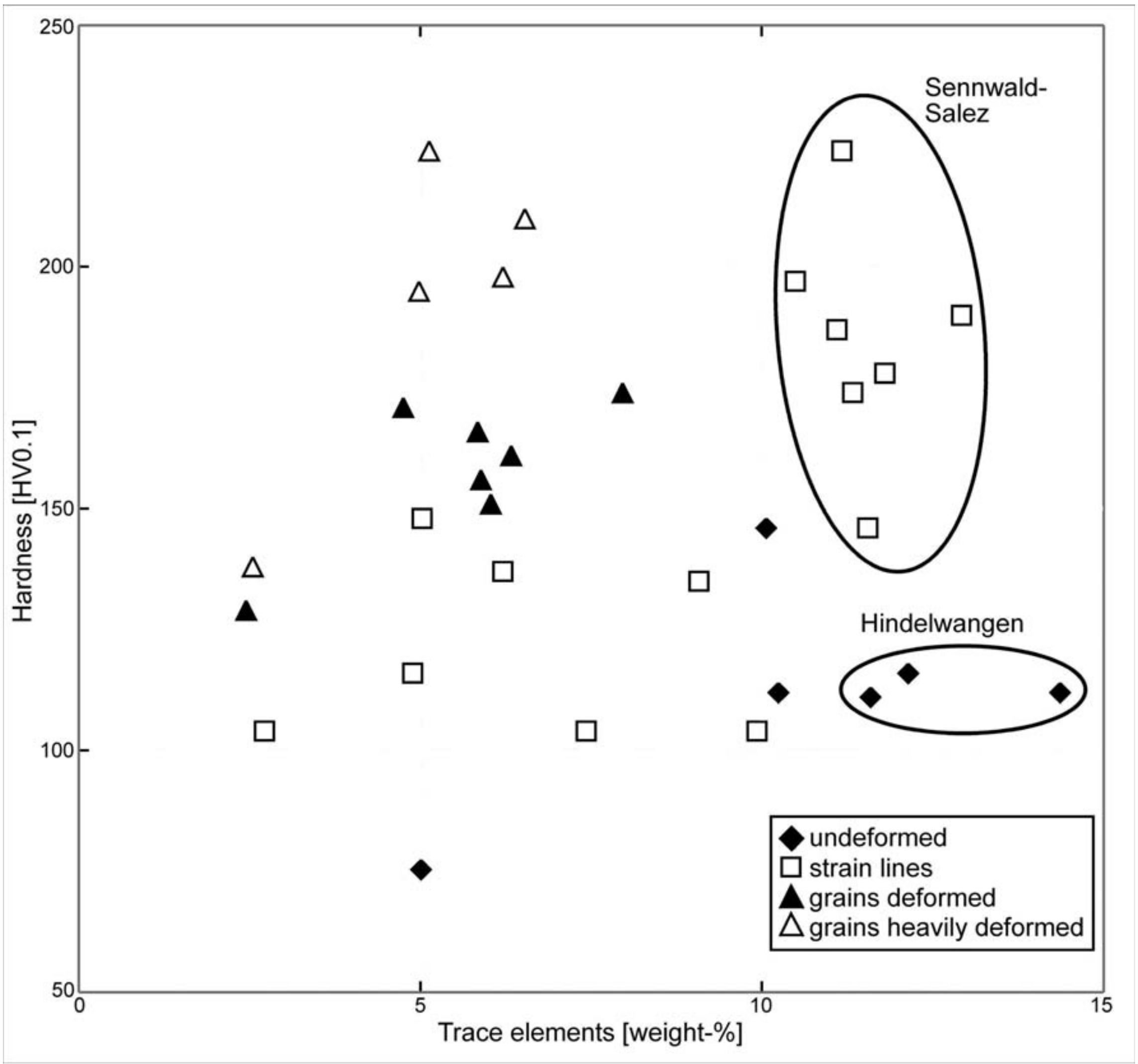


Fig. 7.20: The hardness of the Salez type axes, depending on composition and cold work (after Kienlin/Bischoff/Opielka 2006, 460 fig. 4).

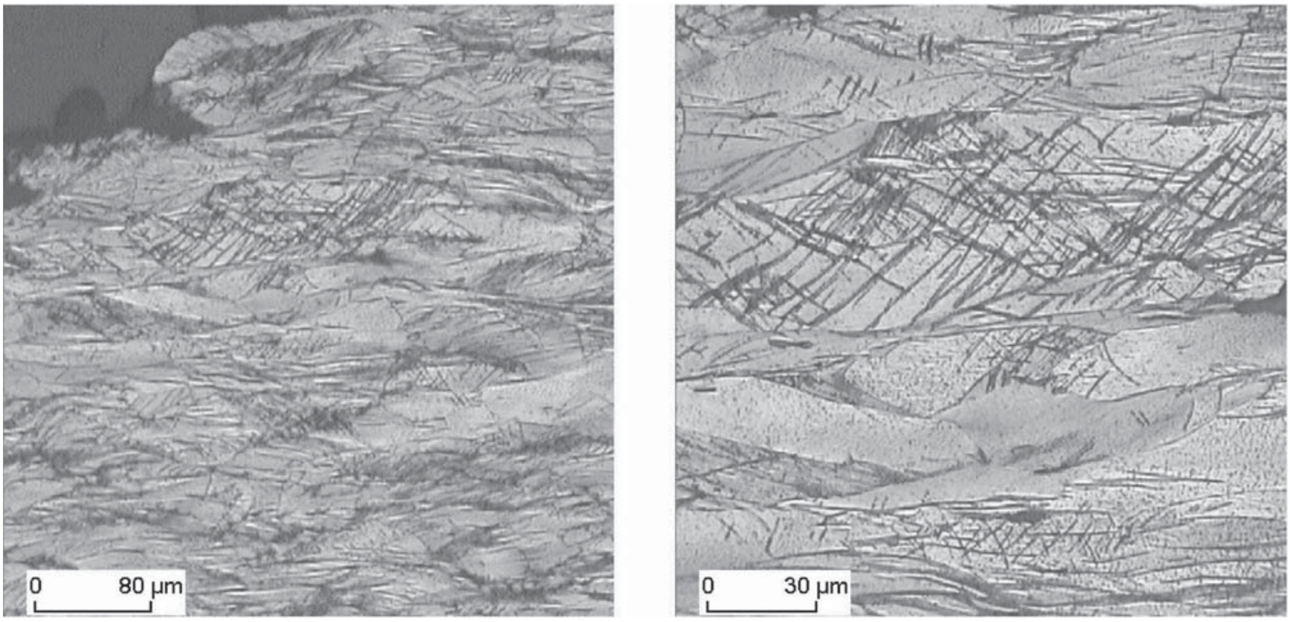


Fig. 7.21: Stronger cold work with strain lines and deformed grains in a Salez type axe from Feldkirch, Vorarlberg, with a lower impurity content (after Kienlin 2008a, 515 tab. 29).

context of production – have justified a preference for this material over copper of the kind used for the axes from Sennwald-Salez. There is no reason to suppose, however, that these 'normal' axes required a stronger reworking in order to produce the desired shape. It is questionable whether the intensity of smithing can be explained solely by the necessity of finishing the axes. Rather, cold working was carried out to increase the hardness of these axes, which in the as-cast or recrystallised state differed only slightly from that of pure copper and put limits on use. In part during the final step a reduction in thickness of more the 45 % was reached without further annealing. This clearly indicates that a strong interest in the mechanical properties was decisive for this kind of treatment.

As with Sennwald-Salez and Hindelwangen, however, it is necessary to have a closer look at this 'optimisation'. Some axes show markedly elongated grains and considerable work hardening was obtained (fig. 7.20). With hardness values of about 200 HV, these specimens reach or surpass the axes from Sennwald-Salez. In contrast to Sennwald-Salez, however, considerable time was required to achieve this result. Great effort was put into the final cold work profiting from both the ductility of this type of copper and its continuous increase in hardness with high reduction in thickness (Lechtman 1996; Junk 2003; Kienlin 2008a, 263–264 figs. 54 and 55). But such a manipulation to an optimum was not the norm, and there are a great number of microstructures with only moderately deformed grains. In this group we still find values of more than 150 HV, yet it is clear that hardness was not taken to the highest achievable values. It was obviously of primary importance to increase significantly the hardness compared to the starting point of an as-cast or recrystallised microstructure. Often the full potential of a work hardening was not achieved – either with regard to efforts required in production or demands on mechanical properties during use. Once again it is apparent that there were different levels of consistency with regard to the needs of the 'consumer' or user.

7.3.3 Salez: Distortions in Technological 'Progress' and the Spread of Tin Bronze?

Salez type axes show characteristic deviations in the strength of cold working. These may be due both to variability in the raw materials used, and in more general terms to their chronological position in the transition to Early Bronze Age fahlore copper when a readjustment of metalworking traditions took place. However, it is apparent that even in processing the fahlore copper of the Sennwald-Salez and Hindelwangen axes the same fundamental routines were followed as in the production of 'normal' axes with lower trace element contents, although they were adapted to the specific properties of the copper used. Thus in the context of metal processing, there are no compulsive arguments against the use of this type of copper, and the exploitation of specific ore deposits has been suggested (Krause 1988). Less likely, an alloying with antimony or nickel is also thought possible (Bill 1997), and in a local or regional context it remains open whether other types of copper would have been available for exploitation. The question then arises what factors could speak for a deliberate production of copper rich in trace elements such as antimony, arsenic etc. or rather the selection of corresponding ores.

Attention has been drawn to the considerable hardness of the Sennwald-Salez axes, and to a lesser extent – in the as-cast state – of the Hindelwangen ones. It is likely that, slightly contrary to the context of production, the mechanical properties of these axes caused them to be held in high esteem. Alongside these there are axes with lower trace element levels that reached comparable hardness values after stronger cold work. With regard to use there would not necessarily have been any discernible difference. What does, however, distinguish the two groups is the colour of the Sennwald-Salez axes, which is closer to silver and deviates from the reddish colour of copper to a much greater extent (Lesniak 1991, 147–155; Bill 1997, 251). It is possible that their conspicuous colour and high hardness (possibly not just functionally understood) together merited an additional significance in social or ritual practices. In a more pragmatic way (and the same holds true for tin bronze) a copper conspicuous by its colour might have guaranteed good mechanical properties across one or several steps of exchange, for the durability of 'normal' axes would have been assessed with much less certainty without knowledge of the production parameters (i. e. strength of cold hammering).

Irrespective of such variability the good properties of most of the Salez axes should be pointed out when compared to neighbouring regions, where Neyruz type axes further west and Saxon type axes from eastern central Europe in part consist of tin bronze (fig. 7.22). This comparison touches on questions of the chronological relationship of the Salez, Neyruz and Saxon types already mentioned in chapter 7.1 (Abels 1972, 9–10; Krause 1988, 223–224; Hafner 1995, 96–98, 141–146; Bartelheim 1998, 47–50; Rassmann 2005, 471–478; Kienlin 2008a, 113–120, 280–291). While their mutually exclusive distribution suggests roughly the same date for these forms, it is debatable whether these axes were contemporary during Early Bronze Age A1, or whether the Salez type represents an earlier stage of development because of the absence of tin. In fact, the typical solution to the differential usage of tin is that the Salez axes are seen as 'somewhat' older (Krause 1988, 223), and/or the tin-alloyed pieces of the Neyruz and Saxon type are put into Early Bronze Age A2 with only the copper ones remaining in Early Bronze Age A1; and some would even date all the Neyruz and Saxon axes to EBA A2 (cf. Abels 1972, 9–10; Hafner 1995, 96–98, 141–146; Bartelheim 1998, 47–50).

There is no independent evidence to solve these chronological problems. Some of the arguments mentioned are circular, because they are derived from metallurgy/composition themselves. It is equally possible, therefore, that all three types represent a period during which particular sorts of fahlore copper and tin bronze coexisted and provided alternatives in terms of mining and smithing

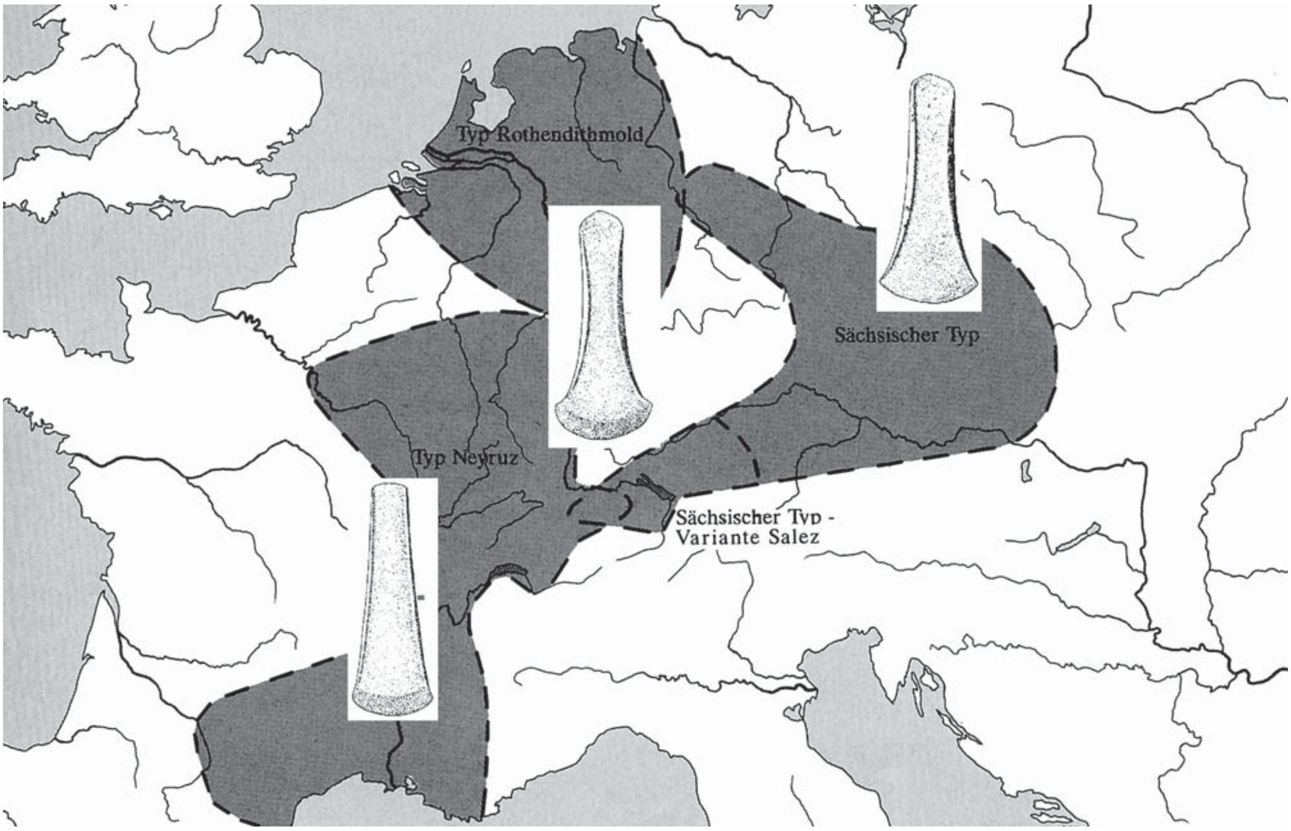


Fig. 7.22: The distribution of Salez type axes in a wider central European setting between Neyruz type axes and related forms to the west and Saxon type axes to the east (after Hafner 1995, 145 fig. 70).

traditions, mechanical properties, colours, smells upon melting or social ties related to their procurement. It should be considered that the access to 'competitive' fahlore copper had effects on the acceptance of tin alloying and contributed to a delayed adoption of this innovation in the area of the Salez axes. For metallography shows that with the juxtaposition of fahlore copper and low-tin bronze there were initially different options. With its specific combination of antimony, arsenic, nickel and silver, fahlore copper had casting properties comparable to tin bronze (Lesniak 1991; Lechtman 1998; Kienlin 2008a). Its conspicuous colour might have attracted attention for symbolic purposes such as use in (prestigious) weapons and ornaments, and a majority of Salez axes reached hardness values that in no way fall short of neighbouring Neyruz and Saxon type axes (see below; Kienlin/Bischoff/Opielka 2006; Kienlin 2008a).

The processing of fahlore copper required flexibility, and different 'qualities' of the available copper led to different results. Thus, the production and properties of the axes were not completely under control and partly depended on the variable properties of the raw metal used. Certainly, herein lies one reason why, after a transitional period when tin contents still fluctuated (e. g. Saxon and Neyruz types), alloying came to predominate when tin became generally accessible. But the main difference between working fahlore copper and tin bronze at this stage did not reside in their workability or in the possibility to produce attractive weapons and ornaments or good implements and tools. It is the ability to do so on a regular basis that makes the difference. For on the fahlore side trace element contents above 6 % to 7 % on the whole are rare. This is the case even among the Salez axes, somewhat more so for the Saxon type and in particular for Neyruz axes which consist of relatively pure copper (figs. 7.14 and 7.20; for the latter see also below in chapter 7.4).

Obviously against a background of a decentralised, possibly kinship or community-based approach to mining (see chapters 5.4 and 8; Kienlin/Stöllner 2009) such metal was difficult to obtain from specific ore deposits and/or involved knowledge of a specific smelting technique that was not generally available. Setting aside cultural preferences, which may have added further complexity to this process, it is likely that communities without regular access to such fahlore copper would have taken to tin bronze rather quickly. Thereby exchange networks were established which eventually proved more 'successful' when the tin supply stabilised. Communities, on the other hand, in an area with either direct access to 'good' fahlore deposits, or at least to corresponding copper, might have opted for the 'traditional' technology considerably longer and relied upon the extraction of specific ore deposits that eventually fell short of satisfying 'demand'. With the benefit of hindsight we see 'progress' and increasingly better solutions in terms of the working and properties of copper and copper alloys, when in fact there were alternative trajectories and

change towards the 'superior' in modern terms was far from immediately apparent. As a result our approaches often are reductionist. We fail to adequately understand the technological choices taken by people who depended on their local cultural background as much as they relied upon the mechanical and chemical properties of copper and tin bronze.

7.4 From Copper to Bronze II: Local Traditions and Long-term Change

The Saxon type axes provide another example of this transitional period to the general acceptance of tin bronze. Unlike the Salez ones discussed above, in this case the coexistence of copper and bronze axes provides the opportunity of a direct comparison of mechanical properties. The above suggestion is confirmed, that the advantages of bronze over contemporaneous fahlore copper were by no means as straightforward as widely held notions of technological progress and the superiority of tin bronze have us believe. A more nuanced approach to the spread of this innovation is required, and a comparison of Saxon and Neyruz type axes at the end of the following section may illustrate two such regional traditions. Here, alloying with tin had different effects on metalworking according to regional preferences and raw material supplies. Finally, the example of Lanquaid type axes and younger axes of our Bronze Age horizon 2 (see chapter 7.4.2) will be used to examine the effect of regular alloying with higher percentages of tin on the production and properties of such implements in a long-term perspective.

7.4.1 Copper and Bronze in Saxon Type Axes of Eastern Central Europe

It is unknown what tin content precisely marks the beginning of deliberate alloying. Although tin is not found in larger quantities in copper ore deposits exploited during the central and south-eastern European (Early) Bronze Age, traces of tin may still have been introduced as an impurity during smelting. In some cases low tin contents may be the result of the degradation of originally high-tin bronze by re-melting and mixing with copper (Kuijpers 2008, 22–23). However, tin contents below 1 % would have had little effect on the workability and properties of copper. Hence it is unlikely that such an 'alloy' would have been recognised or deliberately created, and there are indications that metalworkers were trying to keep up tin contents and avoided 'spoiling' their bronze by mixing it with copper (Spindler 1971; Liversage 1994; Pare 2000; Krause 2003, 207–224).

In fact, among the Saxon type axes which were examined there are two more or less distinct groups that may for good reasons be regarded as unalloyed copper and tin bronze respectively (for the Saxon axes sampled for this study see chapter 7.1, appendix II and fig. 7.14; for the following discussion this data is combined to a series of previously examined Saxon type axes published in Kienlin 2008a, 157–186). The first group has tin contents below detection limit to around 0.8 %, and trace elements sometimes adding up to about 10 % to 11 % (plus, of course, sample no. 166 with an extraordinarily high value above 16 %; see chapter 7.2). On the other hand, there are axes that contain tin in higher concentrations. These tend to have lower trace element contents than the unalloyed samples. Refining has been suggested for this group (Bertemes 1989, 154, 161–162), but strongly fluctuating tin contents render this possibility improbable. Refined copper would have allowed better control over the effects of the tin alloying. In practical terms, however, with such a procedure trace elements that are beneficial to the mechanical properties would have been removed with considerable effort, only to then (tin) alloy again with very differing consequences. Rather, it is likely that ('good') copper rich in trace elements was distinguished from ('poor') copper with low trace element contents, and the scarce alloying element tin was preferentially used in order to improve the mechanical properties of the latter group (Kienlin 2008a, 282–283; see also Liversage 1994, 92).

This second group has tin contents from about 1.7 % to 11.2 %, which are regarded as the result of deliberate alloying. There may remain some doubts for several pieces at the lower end of tin contents. But about 2 % tin are thought beyond impurity levels by most authors (see above), and this is certainly true for the higher tin contents that approach the 10 % value often cited as the optimum tin bronze aimed at in prehistory. As such, however, the Saxon type axes are noticeable for the variability of their tin contents, and it is quite clear that a 10 % tin 'standard' never really was established. Variability of tin contents in Saxon type axes may be the result of poor knowledge of alloying methods at an early stage. More likely it reflects differential access to tin. In any case, working did not allow for these differences: Irrespective of their actual tin content these axes were regarded as 'alloyed', and their final cold working followed a routine slightly different from the copper ones (see below). Langquaid type axes, on the other hand, sometimes have very high tin contents in excess of 10 % (see chapter 7.4.2). This may reflect either better availability of tin (and a somewhat later date of type Langquaid; see discussion in chapter 7.1), or its preferential use in Langquaid axes, that – judging by their form – may have been perceived as 'weapons' rather than 'tools'. Saxon axes, meanwhile, might have carried stronger connotations of multi-purpose 'implements' less apt to the 'expenditure' of tin. In any case, some Langquaid axes have tin contents beyond the mere improvement of mechanical properties. Later on there is clear evidence that from a purely functional perspective somewhat lower tin contents came to be seen as sufficient for the production of widespread implements such as Late Bronze Age socketed axes (Liversage 1994, 78–79, 90–92).

Both fahlore copper and tin bronze could be cast and worked into weapons or implements, and from figures 7.23 and 7.24 it is apparent, that there is a large overlap of the mechanical properties, i. e. the hardness as measured on the metallographic samples, of both groups. Among

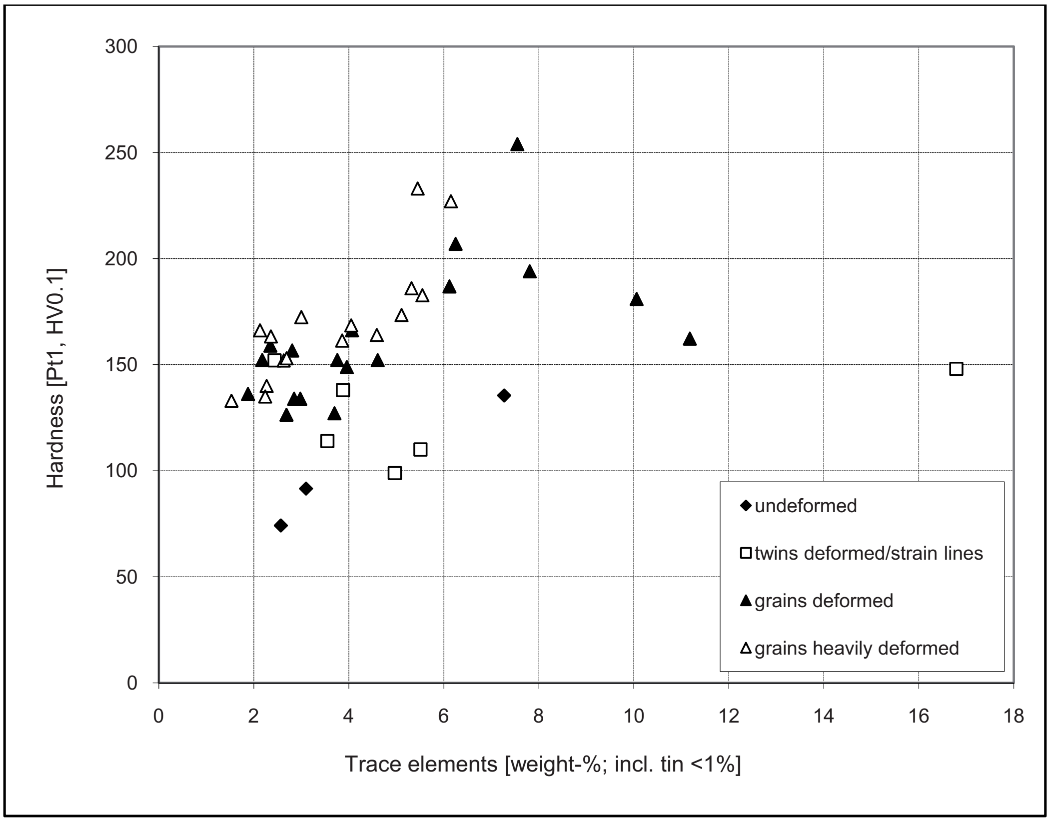


Fig. 7.23: The hardness of the unalloyed Saxon type axes, depending on composition and cold work (sum of trace elements inluding traces of tin < 1 %; Saxon type axes of this study combined to a series of previously examined axes of the same type: Kienlin 2008a, 179 fig. 43).

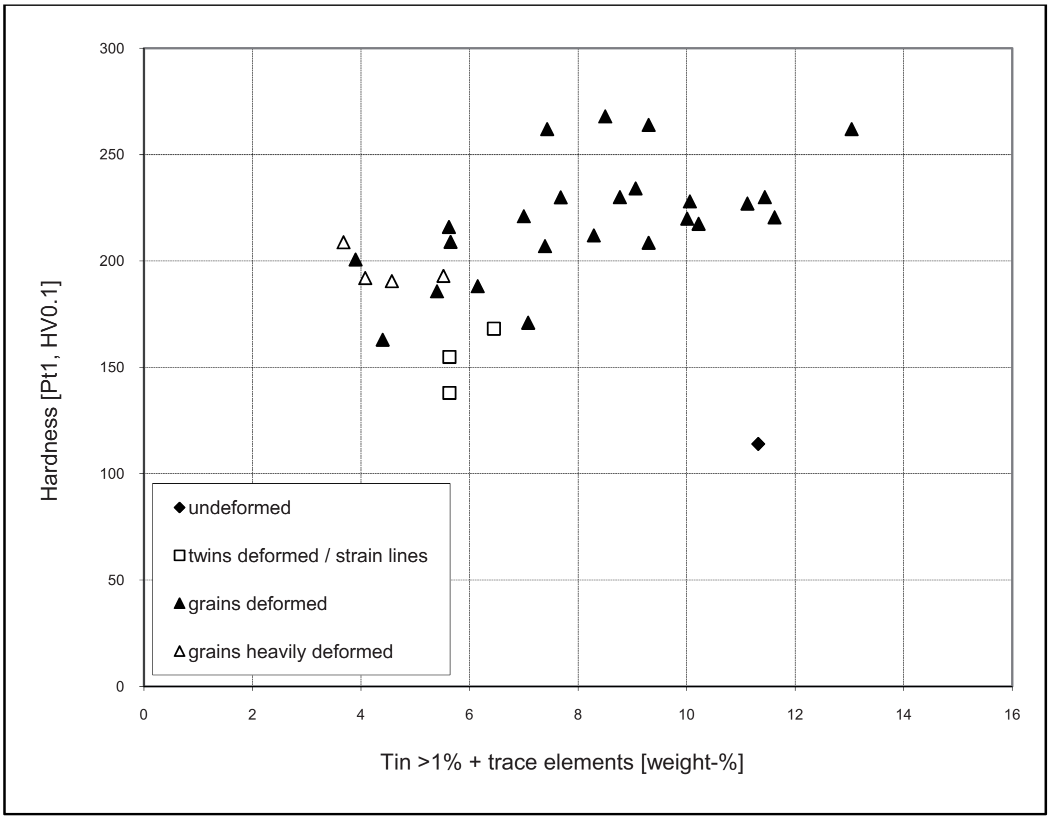


Fig. 7.24: The hardness of the tin bronze Saxon type axes, depending on composition and cold work (tin > 1 % plus trace elements because of their combined influence on solid solution hardening and work hardening; data of this study combined to a series of previously examined axes: Kienlin 2008a, 179 fig. 43).

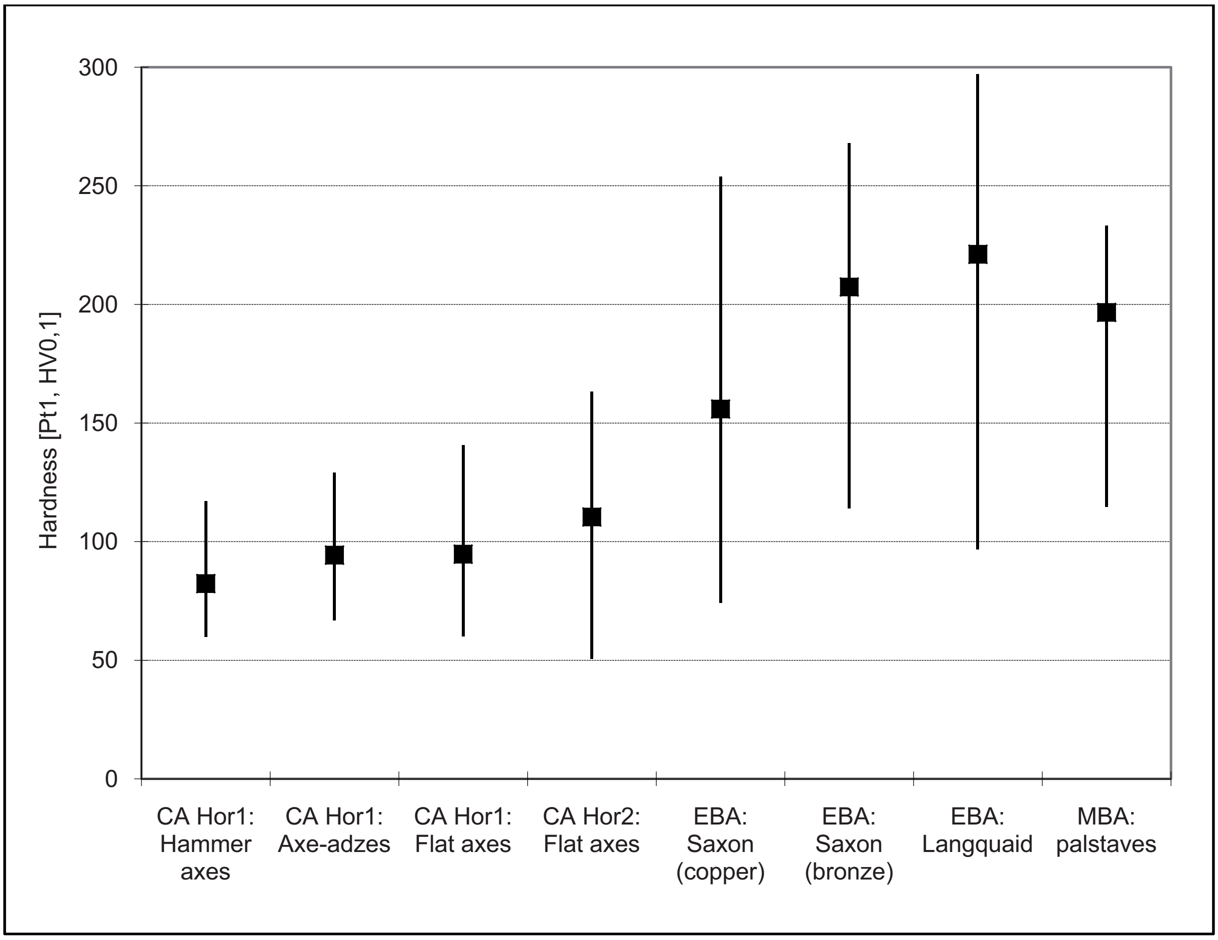


Fig. 7.25: Comparison of the average hardness, minimum and maximum hardness values of all Eneolithic/Copper Age and Bronze Age axe types examined.

the copper axes without tin there are three pieces with a fully recrystallised microstructure without obvious signs of final cold work (sample no. 125 of this study; sample nos. 204006 and 213501 from Kienlin 2008a). As a result of solid solution hardening (sample no. 125: 135.5 HV; sum trace elements: 7.3 %), small grain size and possibly incomplete stress relief during annealing (sample no. 204006: 91.6 HV; sample no. 213501: 74.2 HV), their hardness is relatively high, i. e. above the 50 HV given for pure undeformed copper. However, with readings below 100 HV two of these clearly are an exception in this group (fig. 7.23). Corresponding microstructures without final cold work or with only a minor deformation such as in sample no. 162 (hardness: 98.9 HV; sum trace elements: 4.8 %) do not represent the typical approach to the working of these axes.

Instead, with a stronger cold working we typically see hardness values between roughly 130 HV and 180 HV, with occasional values up to about 250 HV (fig. 7.23). Hardness values up to 150 HV were occasionally reached in Eneolithic/Copper Age axes as well. However, with an average of 94.7 HV for Eneolithic/Copper Age horizon 1 flat axes (hardness provided by the [$Cu+Cu_2O$]-eutectic; see chapter 4.2) and 110.4 HV for Eneolithic/Copper Age horizon 2 ones (hardness provided by cold working; see chapter 4.3) the majority of the earlier axes clearly remain below the Saxon type axes with an average hardness of 155.89 HV in the unalloyed group (fig. 7.25). Experimental work shows that such an increase in hardness adds substantially to the durability of such implements (Kienlin/Ottaway 1998). Even without tin alloying the Saxon axes – as well as the Salez ones discussed in the previous section – clearly represent an 'advance' over previous copper axes. Due to both their fahlore type copper composition and their consistent working in terms of a fairly standardised final cold work (see below), their (good) properties became increasingly predictable, possibly paving the way to a shift in the perception of metal and the more frequent presence of copper implements in the domain of mundane day-to-day activities.

In the tin bronze group as well, substantial solid solution hardening can be observed in one case (sample no. 213004, recrystallised without final cold work: 114 HV; tin: 9.86 %). However, it did not affect the perception and use of the axes, because pieces with little or no deformation in a final step of cold working are an exception ('undeformed' and 'twins deformed / strain lines' in fig. 7.24). Comparable to the unalloyed axes, a more or less consistent final cold work is the rule (see below), and hardness values thereby achieved typically fall into the 160 HV to 230 HV range, with peak

values at 262 HV, 264 HV and 268 HV (sample nos. 204002, 204013 and 214001 from Kienlin 2008a). This is slightly higher than the maximum hardness in the unalloyed fahlore copper group (sample no. 204011: 254 HV from Kienlin 2008a), but clearly there is a wide overlap of both groups in the 150 HV to 250 HV hardness range. Hence, specific axes known to consist of 'good' copper drawn from particular ore deposits or exchange networks were equivalent in their properties upon production and use to axes known to consist of the new material 'bronze' created by alloying.

There were alternatives, and quite obviously tin bronze was not introduced or accepted into existing traditions for mechanical properties that were unknown previously or not otherwise obtainable. With an average hardness of 207.33 HV in the tin bronze group, however, compared to 155.89 HV in the unalloyed one (fig. 7.25), it is obvious that a significantly higher proportion of bronze axes actually reached 'optimum' hardness. Among the fahlore copper axes, pieces with trace element contents below about 6 % to 7 % prevail. With the forging technique applied (see below) this set a limit to hardness values achieved in a large number of these axes to around 130 HV to 180 HV (fig. 7.23). On the other hand, among the Saxon tin bronze axes there are already frequent pieces with tin contents in excess of 7 % to 8 %. These quite easily reached hardness values in excess of 200 HV (fig. 7.24). Such values were much less often achieved by standard working in the unalloyed group, and they were limited to the rather rare pieces high in trace elements.

Unalloyed axes with a hardness of around 150 HV are by no means deficient, and the implications of these findings should not be stretched in terms of the 'superiority' of tin bronze. In the end, when tin supplies stabilised, bronze offered a better basis for the regular production of good weapons or implements. But initially, with heavily varying tin contents and low tin bronzes such as in a part of the Saxon type axes, in both the alloyed and unalloyed groups comparable hardness values were achieved (compare figs. 7.23 and 7.24). The axes generally had similar properties upon working and use. This may be due to a lack of the availability of tin or to poor knowledge of the methods of alloying. In any case, the result was a functional equivalence of the axes of the two groups (alloyed/unalloyed). During a transitional period an axe known to be alloyed with tin did not necessarily prove to be superior upon use. Against the background of Early Bronze Age fahlore metal (see also the Salez axes discussed above), this is surely an important reason why tin bronze took its time to win general acceptance in central Europe. This development is usually seen as solely dependent upon access to widespread exchange networks for tin. However, the metallographic examination shows that in considering such phenomena the practical advantages of different types of copper and tin bronze, which were decided upon locally by individual metalworkers, and the acceptance of their products in small communities must also be taken into consideration.

The conclusion that tin bronze was not introduced with previously unknown properties of copper weapons or implements in mind is confirmed by a comparison of deformation rates achieved during the final cold working of Saxon type axes of copper and bronze (figs. 7.26 and 7.27). In both groups there is some variation in the strength of final cold working, which is to be expected under prehistoric conditions of metalworking. Some axes left in the fully recrystallised state, without final cold work, were already mentioned above. In both groups as well there are some axes whose microstructures show strain lines and deformed annealing twins, but grains were not deformed during cold working. The deformation achieved in the final working of these axes may be classified between roughly 10 % to below 30 % reduction in thickness (see appendix I; Northover 1989; 1996; Buchwald/Leisner 1990; Scott 1991; Wang/Ottaway 2004; Kienlin 2008a, 43–75). The increase in hardness achieved at this stage is significant. It certainly did not go unnoticed. Typically, however, a somewhat stronger deformation was aimed at, and in both groups (unalloyed and alloyed) in the majority of axes there are more or less heavily deformed grains pointing at a reduction in thickness beyond 30 %.

This approach to forging may be taken as the 'standard' procedure, but a closer look reveals some significant differences between the copper and bronze axes respectively (figs. 7.26 and 7.27). In the copper axe group a large number of axes show heavily deformed grains corresponding to a reduction in thickness in the 45 % to 50 % range. Three axes even show an extreme elongation of the grains indicative of a reduction in thickness beyond 50 % (see appendix I; Northover 1989; 1996; Kienlin 2008a, 43–75). It is likely that compositional differences were recognised by variations in colour, and differential work hardening with higher trace element contents might also have been noticed. The absence of pieces worked beyond 40 % to 45 % reduction in thickness among the axes with very high trace element contents might be an argument in favour of this assumption (see right half of diagram in fig. 7.26). However, the number of such axes sampled is small, and the initial closeness in cold working behaviour would have impeded the recognition of such differences (see also chapter 4.3 for a related point on arsenic contents and the working of Eneolithic/Copper Age horizon 2 axes; Kienlin 2008a, 170–186 with regard to Saxon type axes). Any such deviations in cold working behaviour might have been negligible compared to the overall increase in hardness achieved anyway. It is suggested, therefore, that there is no systematic correlation of composition, i. e. trace element contents, and the strength of final cold working. Irrespective of composition, forging aimed at a substantial increase in hardness compared to the as-cast or rather the recrystallised state. What is remarkable about the group of copper axes is the very high deformation rates often achieved in this process. Largely irrespective of composition for all arsenical or fahlore copper and tin bronze there is a strong increase in hardness upon initial working up to a reduction in thickness of say 30 % (Kienlin 2008a, 263–264 figs. 54 and 55). This is by far exceeded in many Saxon axes of

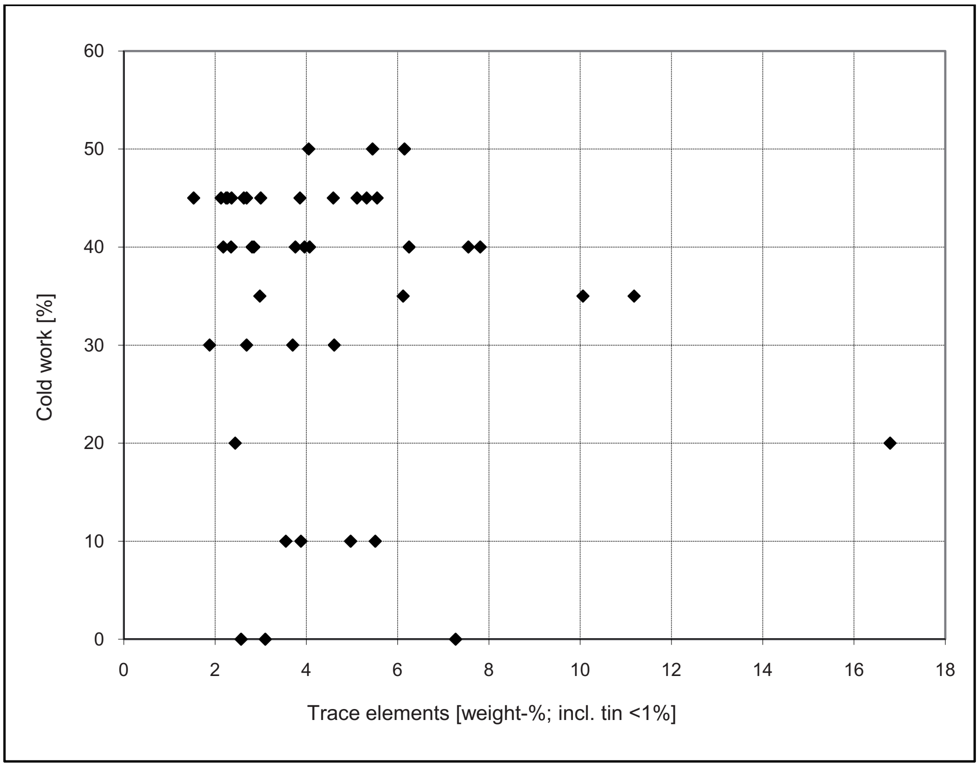


Fig. 7.26: Strength of final cold work in the group of unalloyed Saxon type axes (cold work: % reduction in thickness; note that to simplify this graph the broader ranges given in the text and fig. 7.9 M16 have been reduced to the lowest possible value respectively, e. g. an estimated deformation in the 20 % to 30 % range [i. e. twins deformed and strain lines] will appear on the 20 % line; sum of trace elements inluding traces of tin < 1 %; data of this study combined to a series of previously examined axes: Kienlin 2008a, 179 fig. 43).

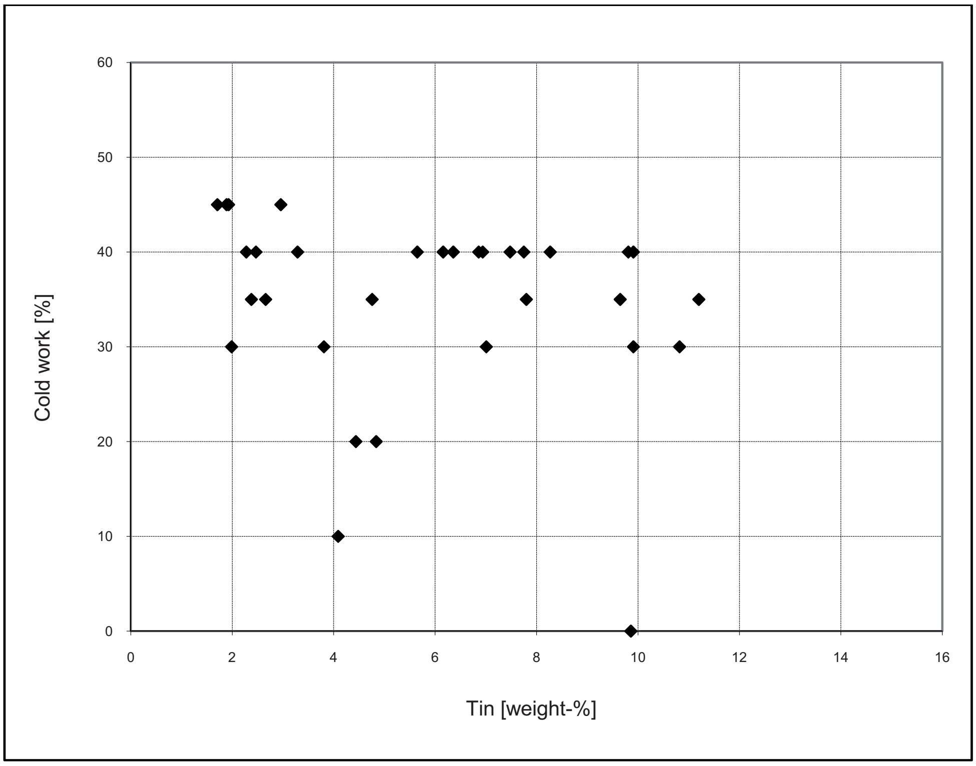


Fig. 7.27: Strength of final cold work in the group of tin bronze Saxon type axes (cold work: % reduction in thickness; note that to simplify this graph the broader ranges given in the text and fig. 7.9 M16 have been reduced to the lowest possible value respectively, e. g. an estimated deformation in the 20 % to 30 % range [i. e. twins deformed and strain lines] will appear on the 20 % line; unlike fig. 7.24 composition is in weight-% tin to illustrate cold work in relation to the deliberately added content of the alloying element; data of this study combined to a series of previously examined axes: Kienlin 2008a, 179 fig. 43).

the copper group. Obviously, this does not apply to all of the axes examined. But there is a clear tendency to work beyond strict functional requirements, that may be termed a specific technological 'style' of unalloyed Saxon type axes in comparison to both the tin bronze axes of this type and contemporaneous Neyruz axes further west (see below). By doing so trace element contents of this group of unalloyed Saxon type axes were translated into rather high hardness values.

In contrast, among the bronze axes there are only four pieces with a reduction in thickness in the 45 % to 50 % range, and none with an extreme elongation of grains (fig. 7.27). The four axes in question have relatively low tin contents. However, it is unlikely that the absence of an equally strong forging among the high-tin bronzes is an effect of reduced deformability or embrittlement in this compositional group. Rather, experimental data show that high-tin bronze as well may be forged up to a much higher reduction in thickness without problems (see Kienlin 2008a, 262–277 for references and discussion). Hence, it is 'culture' or technological choice that brought about modifications to the forging method applied in the production of tin bronze axes. It is tempting, although difficult to prove, that the somewhat stronger cold work found in some of the low-tin bronzes still reflects the older approach to working unalloyed copper (see above), and these pieces in chronological terms cover the earlier part of the transition to bronze. In fact, it is likely that there was such a transitional period, and modifications to traditional practice certainly took time to win general acceptance.

However, of course, we must not date individual axes by either their composition or working. Instead of arranging microstructures into chronological order, it is safer to state that among the bronze axes as well there is some deviation in terms of working. Beyond mere random variation, however, there seems to be a general tendency for deformation rates to stabilise on a somewhat lower level than in the unalloyed Saxon axes discussed above. Since among the tin bronzes too there is no clear correlation of composition and working, forging was apparently carried out to achieve a substantial increase in hardness compared to the recrystallised state. It was insensitive to composition as in the copper axes discussed above. Compared to the working of fahlore copper, however, characteristic modifications occurred. In the unalloyed group the axes' trace element contents in the majority of cases were transformed through a fairly intensive forging into rather high hardness values. With the tin alloyed pieces such high deformation rates are lacking and the cold working remains on a lower level. From the standpoint of the material properties, such as deformability, there are no apparent reasons for this. The impression is that the fact of alloying, i. e. the manipulation of the mechanical properties through composition, was used as an opportunity to reduce the effort required in forging (Kienlin/Bischoff/Opielka 2006; Kienlin 2008a, 170–186).

This development and the use made of tin bronze in the production of Saxon axes is not a matter of course. We may turn here to another group of Early Bronze Age axes from the north alpine region for an impression of the effect alloying with tin had in a different tradition of metalworking (see also Kienlin 2008a, 187–215). Neyruz axes, named after a hoard from the Swiss canton Vaud (fig. 7.28), are trapezoid flanged axes distributed in western Switzerland, while related forms occur across a broad area from southern France to north-western Germany (see fig. 7.22; Abels 1972, 11–14; Mayer 1977, 71–76; Kibbert 1980, 97–99, 157–164). Proper Neyruz type axes have generally lower concentrations of impurities such as arsenic, antimony etc. than commonly found in both the Salez and Saxon types. This pattern has been interpreted as the result of separate exchange systems for metal (Krause 1988, 223–237). Among forms related to type Neyruz, however, sometimes there are higher trace element contents as well, so this group is not entirely homogeneous in terms of copper composition (figs. 7.29 and 7.30). The number of unalloyed axes from the Neyruz group examined is still rather small, and the findings presented require support from a larger data set in future. Still, one gets the impression that in the run-up to tin alloying forging was rather weak and unsystematic (fig. 7.29). This approach apparently was similar to that noted in the group of Eneolithic/Copper Age horizon 2 flat axes (see chapter 4.3). It could be seen as a consequence of the limited work hardening potential of the rather pure copper predominantly used at least in the core area of Neyruz type axes (Kienlin 2008a, 201–215). Against this background, then, the tin-alloyed samples of this type show a tendency for more intense cold working (fig. 7.30). Unlike the Saxon axes discussed above, the adoption of tin bronze evidently led to an intensification of smithing. Composition and manufacturing technique had a stimulating effect upon each other and led to an increased interest in the mechanical properties of the axes. Unlike the Saxon axes, this found expression not only in the use of tin bronze, but also in attempts to increase hardness through stronger hammering.

These two developments should not be judged on the basis of modern expectations as differing 'optimal' implementations of tin alloying. Rather, one encounters motivations and approaches that developed in line with a regional background and should be seen as appropriate according to their specific context. In addition to the unalloyed axes of the Salez type and their fahlore metallurgy, as well as the Saxon type axes 'response' to tin alloying, the existence of further technological traditions can be observed. Over a certain period of time these differed in terms of their implementation of far-reaching trends, such as the spread of knowledge of tin bronze.

7.4.2 Flanged Axes of the Langquaid Type and Bronze Age Horizon 2 Palstaves

Unlike the Salez type axes, which do not contain any tin, and those of the Neyruz and Saxon types, which are alloyed only in part and with strongly fluctuating tin contents, in the Langquaid type axes tin bronze is the norm and high concentrations of around or above 10 % tin predominate. At the same time, the transition to another type of copper

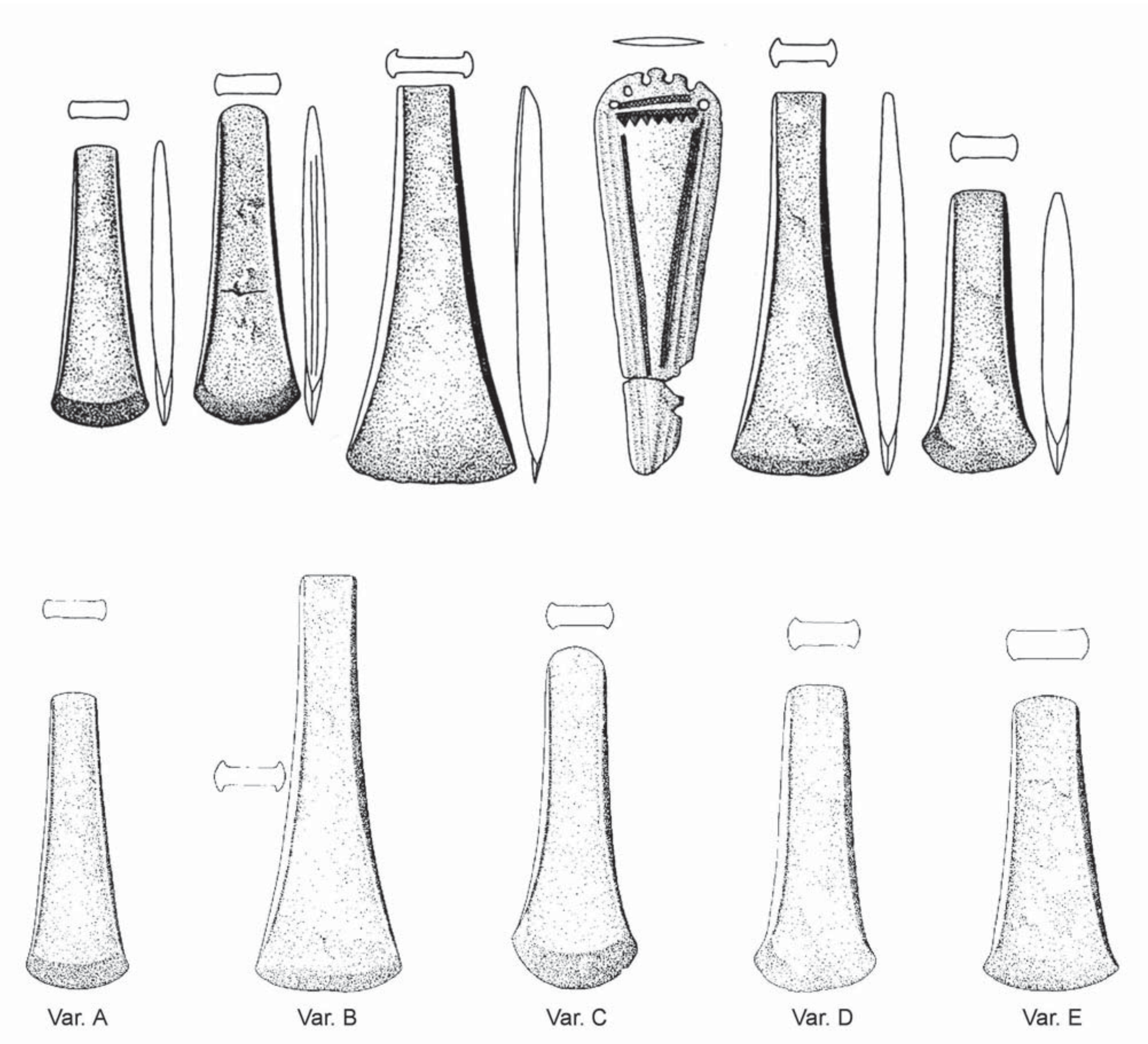
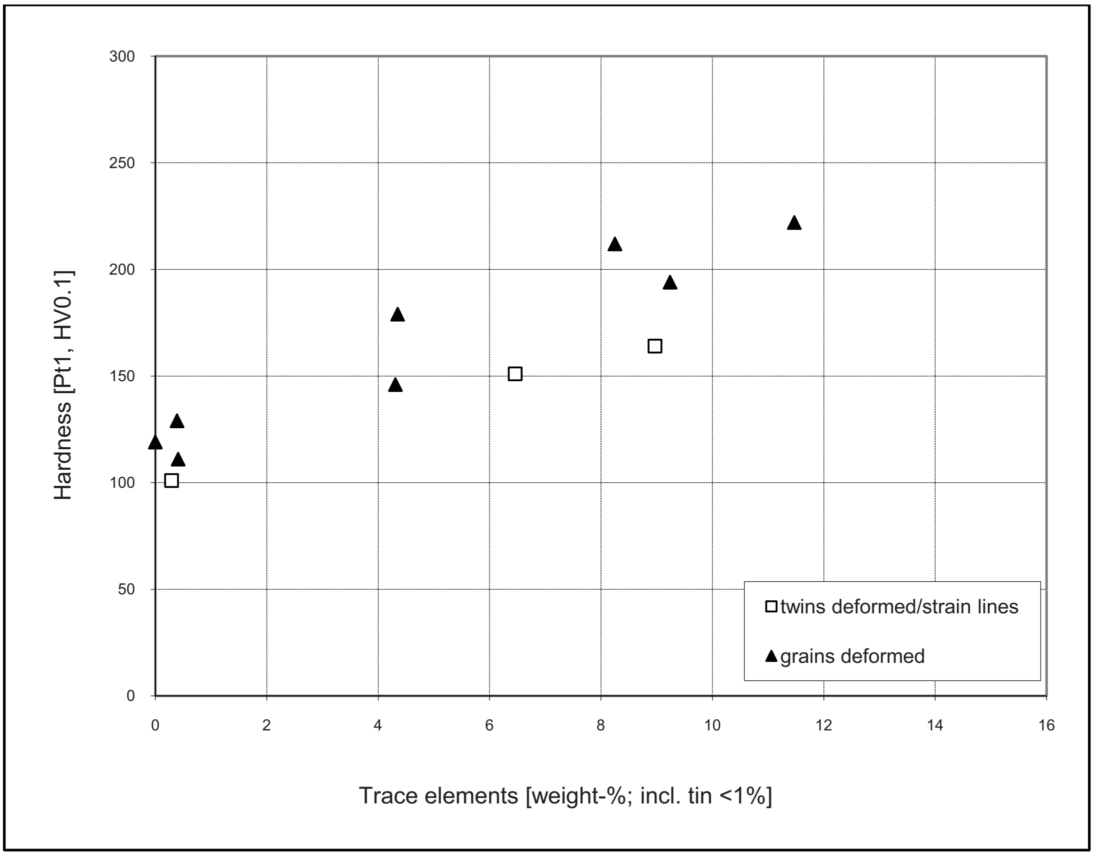


Fig. 7.28: The eponymous hoard of Neyruz, canton Vaud, in Switzerland (above) and the different variants of Neyruz type axes (below; after Krause 2003, 195 fig. 181B; Kienlin 2008a, 14 fig. 2; Abels 1972).

can be observed, the so-called east alpine copper (*ostalpines Kupfer*), which shows comparatively low trace element contents (Krause 1998, 172; Krause 2003, 199). Previously, composition was dependent on a series of factors such as ore selection and smelting method (e. g. type Salez) or on the availability of tin and the control over methods of alloying (Neyruz and Saxon types). In contrast, the Lanquaid axes enable the effect of regular alloying with high percentages of tin on the production and properties to be examined. The following discussion mainly draws on a series of 29 Langquaid axes previously examined and published in Kienlin (2008a, 221–241); these are supplemented by sample nos. 167, 168, 169 and 171 of the present study (see chapter 7.1 and appendix II).

In the older SAM analyses detection of tin was limited to 10 % (e. g. Junghans/Sangmeister/Schröder 1968; see SAM database in Krause 2003). Imprecise readings given as > 10 % or >> 10 % tend to conceal that there are actually tin contents up to 14 % to 15 % (see below). At such concentrations full homogenisation of the δ-phase (more precisely the α/δ-eutectoid) was rarely achieved, and upon working δ-particles, which are brittle, broke up and were dispersed following the flow of the copper matrix. However, despite claims to the contrary, there is no indication that high tin contents in the copper matrix and the presence of the δ-phase precluded working and this was an alloy suitable for casting only. To contrary, there are no systematic differences in the strength of (cold) working throughout the whole range of tin contents from broadly 7 % to 15 % (see below). Irrespective of composition most of the axes were thoroughly worked to raise hardness beyond an already high as-cast hardness (solid solution hardening due to high tin contents). Mechanical properties were important, and this interest clearly points to a practical use of these axes as weapons or implements in the widest sense. On the other hand, tin contents in excess of 10 % from a purely functional perspective are unnecessary. This



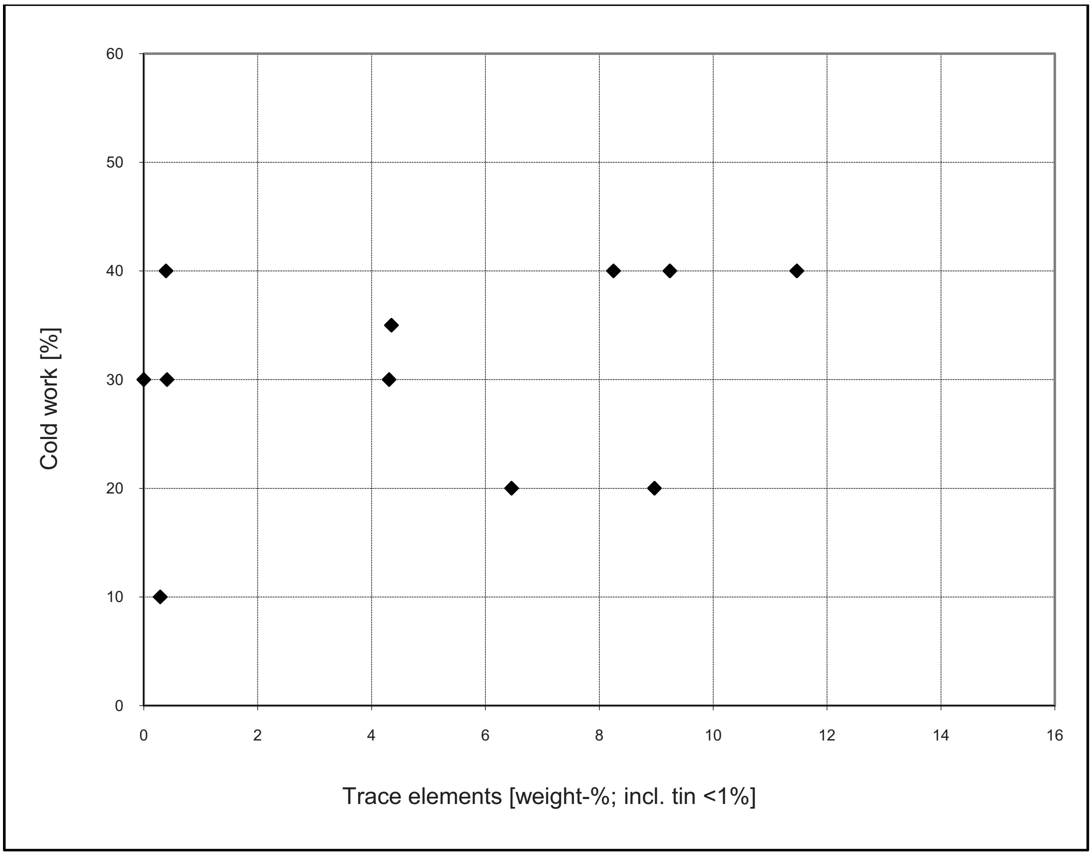
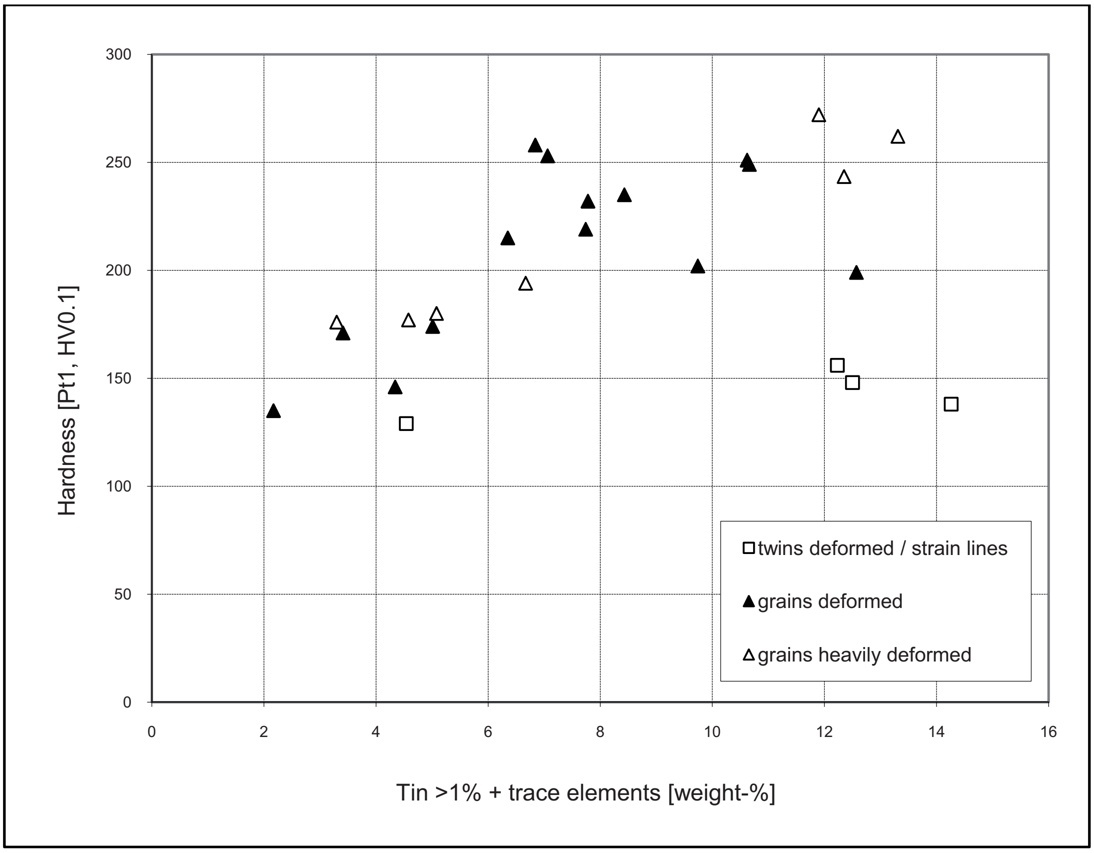


Fig. 7.29: Above: The hardness of the unalloyed Neyruz type axes, depending on composition and cold work. Below: Strength of final cold work in the group of unalloyed Neyruz type axes (cold work: % reduction in thickness; both diagrams: sum of trace elements inluding traces of tin < 1 %; data from a series of previously examined axes: Kienlin 2008a, 208 fig. 47).



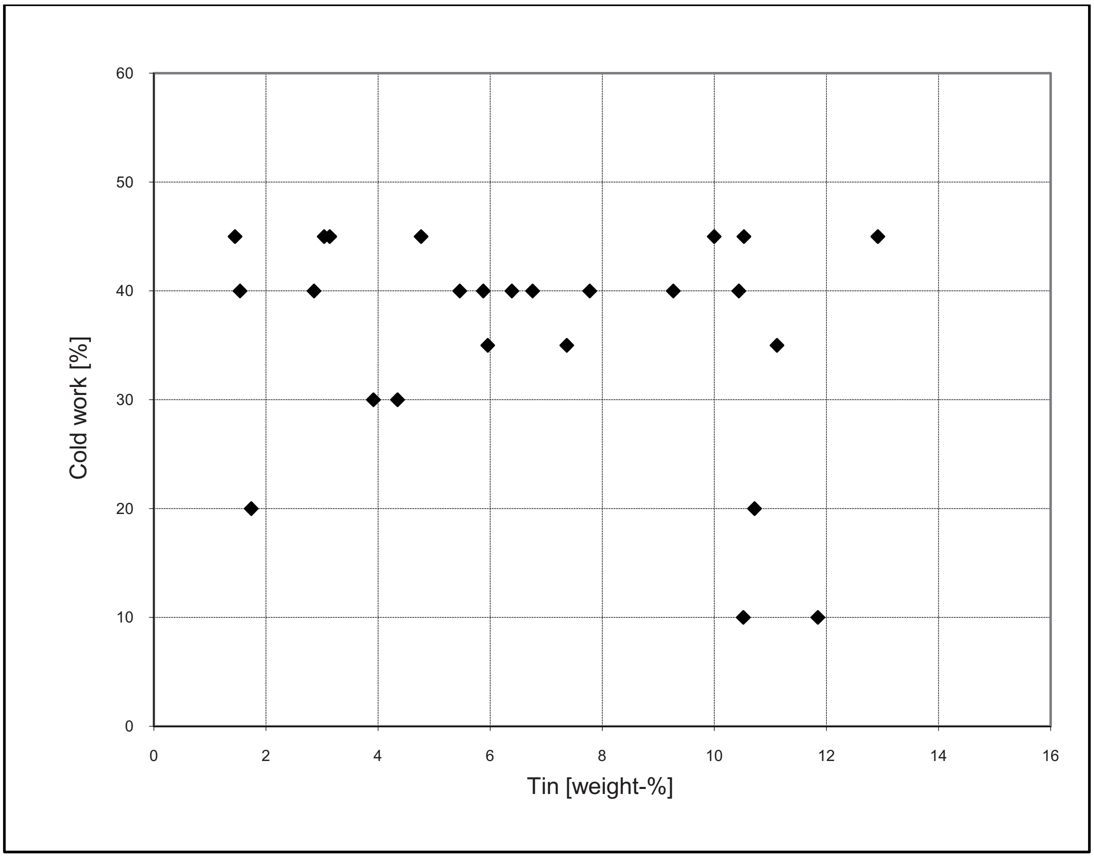


Fig. 7.30: Above: The hardness of the tin bronze Neyruz type axes, depending on composition and cold work (tin > 1 % plus trace elements because of their combined influence on solid solution hardening and work hardening). Below: Strength of final cold work in the group of tin bronze Neyruz type axes (cold work: % reduction in thickness; composition in weight-% tin to illustrate cold work in relation to the deliberately added content of the alloying element; data from Kienlin 2008a, 208 fig. 47 plus sample no. 172 of the present study).

finding hints at motivations beyond the mere improvement of mechanical properties. By their conspicuous blade, large and heavily curved, these axes – even when hafted – might have qualified as weapons rather than as simple 'tools'. They may have borne close reference to their owners as a part of their habitus or as an expression of a specific standing in his (her?) group ('prestige'/'status'?). In fact, some of them were recovered from graves, but this is also true of some of the more 'mundane' Saxon and Neyruz type axes (Kienlin 2008a, 293–312). In the Early Bronze Age of the north alpine region the occurrence of axes in graves (from EBA A2 onwards) is indicative of changes in burial customs rather than in the function and/or meaning of the axes themselves. Tin contents may also depend on the availability of tin, access to long-distance exchange and/or carry chronological implications. However, since Langquaid and Saxon type axes are at least in part contemporaneous deliberate choice also has to be taken into consideration. The high tin contents of the Langquaid axes may reflect a particular interest in display, colour and/or the conspicuous use of tin in their production. Such aspects should be borne in mind, although – due to the nature of our metallographic data – in this section the focus is on the influence of tin on the working and mechanical properties of the axes.

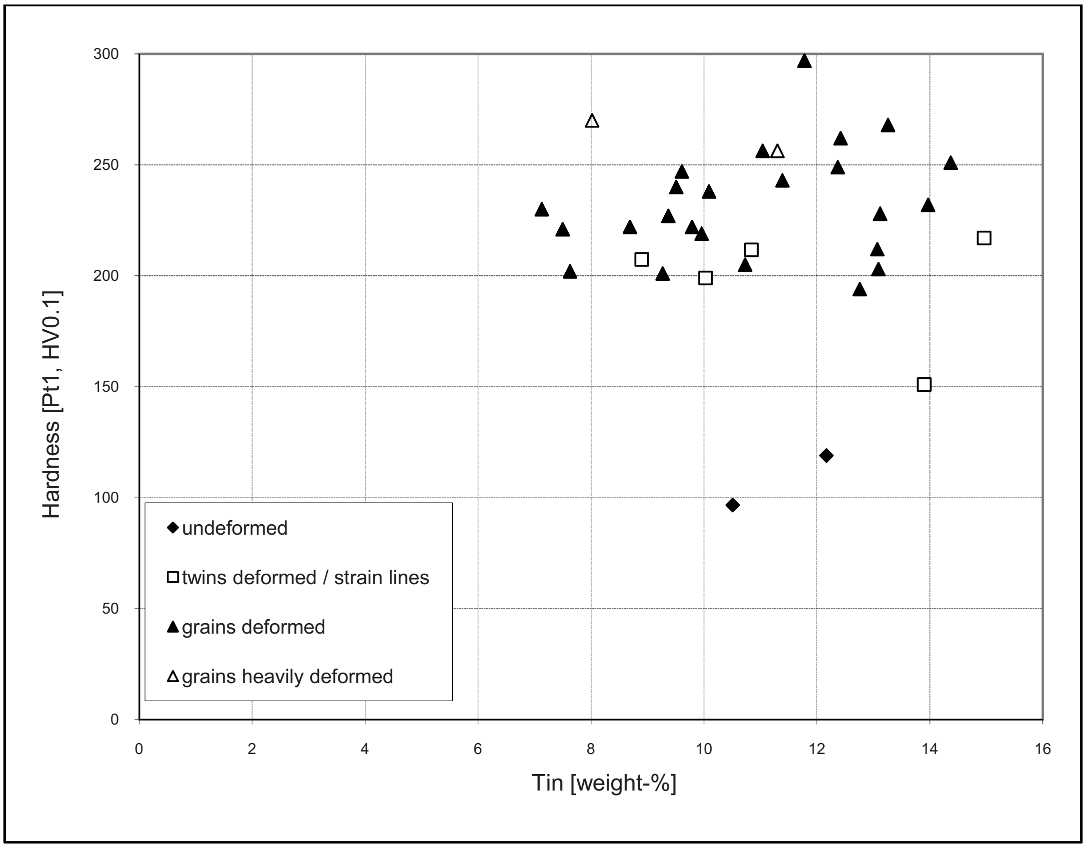
None of the Langquaid axes sampled shows casting grains. Without exception, a fully recrystallised microstructure is found, that was subject to at least one heat treatment of sufficient intensity for complete recrystallisation. In some of the axes there is no more residual coring. In their case a comparatively high intensity of annealing can be supposed with strong homogenisation, although the α/δ-eutectoid is still found in most of these axes. In all samples, annealing twins show that there was deformation preceding recrystallisation. At least a two-phase forging process is the norm. In some of the axes, deformed copper sulphide particles and coring show that in the course of this procedure a fairly high reduction in thickness was achieved. However, this cannot just be interpreted as a shaping operation, because the high flanges of the axes in question and mould finds prove that closed moulds were used. Rather, as a large part of the deformation was done by final cold working it is apparent that higher hardness was aimed for by forging. A considerable increase in hardness is evident in most of these high tin bronzes.

Only two of the Langquaid axes show a recrystallised microstructure without any signs of cold working. In another five samples there are equi-axed grains with deformed twins and/or strain lines that give evidence of a limited cold work in the final step. In the majority of axes a deformation of grains of light to medium strength is apparent, but only two axes show a considerably stronger elongation of the grain structure (fig. 7.31). In comparison with the two groups of Saxon and Neyruz type axes discussed above (respectively unalloyed and alloyed) as well as with the flexibility in approach evidently required in the production of Salez axes (see chapters 7.3 and 7.4.1), there is a standardisation of the final cold work. Microstructures consistently show a reduction in thickness between approximately 30 % to 35 % and a maximum of 40 % to 45 % and corresponding hardness values between 200 HV0.1 and 250 HV0.1 are predominant (fig. 7.31).

After heavy cold working high-tin bronzes may become brittle and suffer a loss of ductility (e. g. Lechtman 1996, 501–502). For this reason, according to Northover (1989, 113), the practicable deformation of such a tin bronze is 40 %, and it is apparent that most of our axes fall into this range. Yet Lechtman (1996, 496 fig. 20, 502) with her 10 % tin bronze achieved a reduction in thickness above 80 %, and even her 13 % tin bronze did not fail until deformed above 50 % (see also Kienlin 2008a, 263–264 figs. 54 and 55). Among the axes examined even those with lower tin contents between 7 % and 10 % typcially do not show deformations above 45 %, though this would have been possible without any problems. It is likely, therefore, that it was not brittleness or reduced ductility that set an end to cold working but rather an established mode of forging.

The emergence of a standardised method of working is evident, with the experienced worker being able to tell from sound and from 'feel' of the metal when hammered how hardness was changing and how hard the metal had become. This working was primarily defined by the effort involved and hardness achieved – more precisely by a considerable and satisfactory improvement of mechanical properties with regard to the as-cast or recrystallised state. With an average hardness of 221.13 HV there is a slight increase compared to the tin bronze group of Saxon type axes at 207.33 HV (fig. 7.25). This is due to the shift in tin contents towards higher concentrations and the absence of pieces with tin values below about 6 % to 7 % and a somewhat lower hardness in the Langquaid group. Still it is obvious that in both groups, among the tin bronze axes of the Saxon type and among the Langquaid axes, a similar approach to working was chosen (compare figs. 7.27 and 7.31). Given the smooth transition between both forms (e. g. 'type' Langquaid I; see chapter 7.1), their joint circulation in the second half of the Early Bronze Age (EBA A2) and broadly similar distribution in parts of eastern central Europe, it is likely that they were produced by metalworkers operating in the same broad tradition. Knowledge of working tin bronze was taken over and handed down that originally developed somewhat earlier, when Saxon axes first were made of bronze, and when this approach was still rivalled by neighbouring traditions such as among the Neyruz and Salez axes.

Similar properties were achieved only for a part of the other types' axes, those that have a high trace element or tin content. However, it is also clear that the use of tin bronze for the Langquaid axes – as previously for the axes of the Neyruz and Saxon type axes – did not lead to hitherto unreached hardness values. Rather, there is a stabilisation of the mechanical properties at a high level. With regard to the perception of this group of axes, a higher level of certainty concerning their properties was the likely result. This also was important in the exchange of such axes, especially across intermediate stages with no immediate knowledge



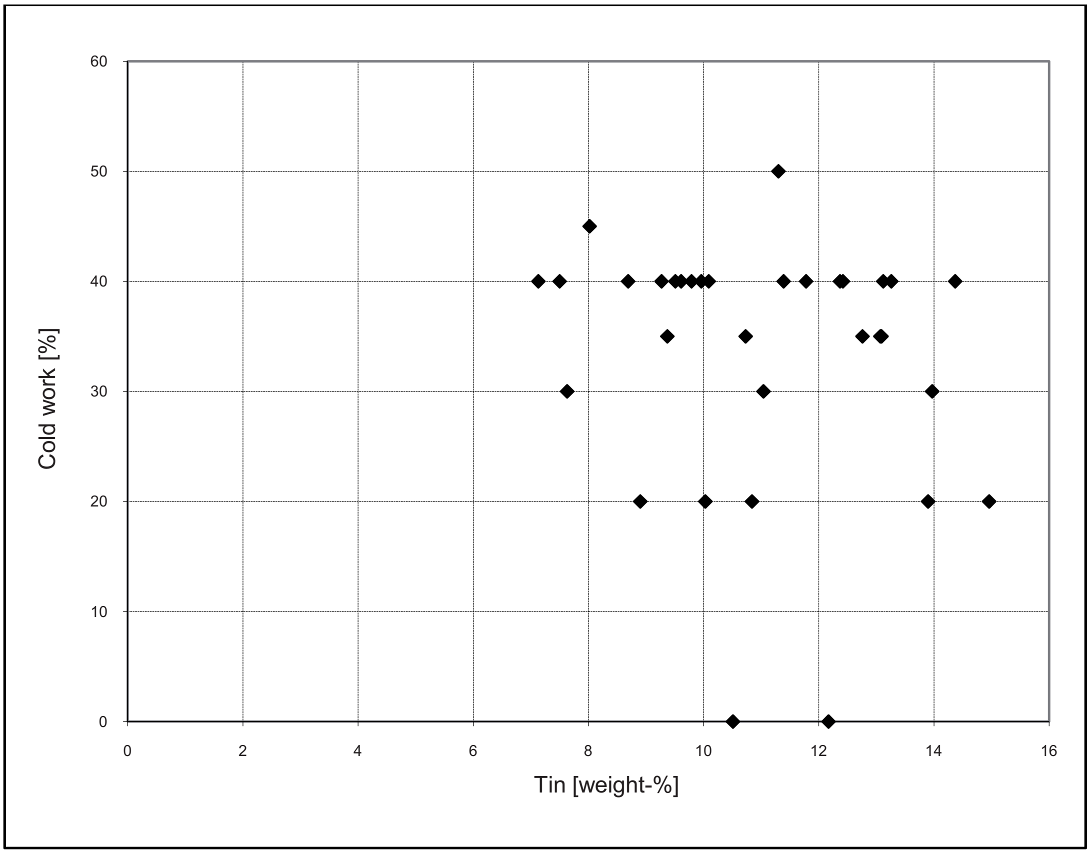


Fig. 7.31: Above: The hardness of the Langquaid type axes, depending on composition and cold work. Below: Strength of final cold work in the group of Langquaid type axes (cold work: % reduction in thickness; data from Kienlin 2008a, 236 fig. 50 plus sample nos. 167, 168, 169, 171 of the present study).

on the receiving side of their production parameters. Their use certainly became more a matter of course. On a higher level, the production, circulation and overall general importance of metal for the society of the time will have stabilised. Here is the actual transition to the metal ages – a development that can be qualified more precisely with reference to the microstructures than solely by allusion to tin alloying on a regular basis. The use of high-tin bronze is accompanied in the case of the Langquaid axes by a standardisation of the forging technique, that cannot be taken as given. There is a stabilisation of the deformation rates that is not solely attributable to the material properties, such as deformability, for there would still have been a great deal of scope upwards, but rather to an alignment of procedure and similar expectations of the properties of the axes. The 'quality' of the Langquaid axes is not solely down to their composition, but rather to a stabilisation of the manufacturing processes in general, and especially of (cold) working. Only the two aspects together enable a satisfactory understanding of the importance of metal in this period. Beyond the regional differences previously discernible – the use of different sorts of copper and the different reactions to tin alloying –, a standardisation of Early Bronze Age metallurgy is evident, that extends beyond the exchange of finished products or tin. What can be discerned is a standardisation of metallurgic knowledge and a more intensive participation of local producers in cross-regional communication processes.

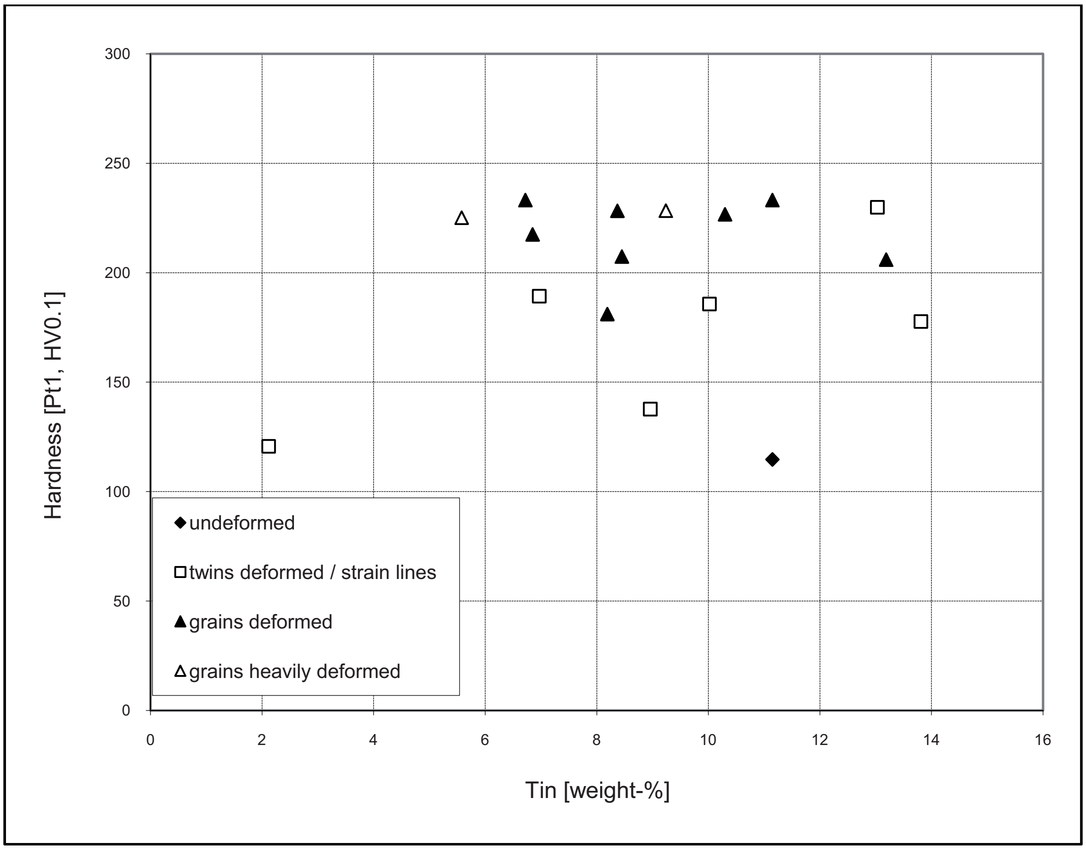
The number of younger axes examined from our Bronze Age horizon 2 is rather small and heterogeneous in terms of different types such as various forms of palstaves and two winged axes of (early) Middle to Late Bronze Age date (see chapter 7.1). Hence there are restrictions on an attempt to trace the development of the tradition outlined above into the later phases of the Bronze Age. The axes sampled in this group have tin contents between an exceptionally low 2.12 % in sample no. 70 and a maximum value of 13.81 % (sample no. 71) with most values falling in the roughly 6 % to 11 % concentration range (fig. 7.15). Thus, the very high tin contents found in some Langqauid type axes are not systematically taken up, and a more 'economical' approach to the use of tin was established. The same tendency can be observed in analytical data of later Bronze Age weapons and implements throughout central and south-eastern Europe (e. g. Liversage 1994, 75–92, 96–97; Rychner/Kläntschi 1995, 61–62; Rychner 2004). All basic production parameters remained unchanged, however, such as casting and multi-stage working with an interposed annealing, and in the final step clearly an increase in hardness was aimed at by cold working (fig. 7.10). Depending on composition and the reduction in thickness achieved, most of these axes have hardness values between roughly 180 HV and 230 HV (fig. 7.32). Lower values are found in the one axe that went without final cold working (sample no. 73), and in two axes with deformed twins and/or strain lines but without a deformation of grains (sample nos. 50 and 70). Comparable variation was evident in the above discussion on groups of Saxon and Langquaid type axes etc. It is to be expected under prehistoric conditions. At the other end of the hardness scale readings around and above 250 HV, which were reached in a greater number of Langquaid axes, are missing in the group of younger axes examined. Apparently, this is a side-effect of the trend observed to somewhat lower tin contents, and the average hardness of this group is at 196.62 HV (fig. 7.25). However, it is thought unlikely that such minor differences at generally high hardness levels (e. g. 230 HV 'only' instead of 250 HV) were noticed upon use and represent a 'deterioration' of the axes' quality during the later Bronze Age. Rather deformation rates show that there was still an emphasis on a consistent final cold working, and typically a reduction in thickness beyond 30 % to 35 % was aimed at and achieved (fig. 7.32). From the available data, however, it is difficult to tell, if forging took place in the 'Langquaid tradition' outlined above. The fact that there are only two axes in the beyond 45 % deformation range, i. e. with elongated grains (sample nos. 115 and 116), certainly suggests so; but the total number of axes in this group or horizon is rather small for such a conclusion to be drawn with certainty. On the other hand, some of the palstave forms examined are derived from Saxon type axes, and in their earlier phases such forms are broadly contemporaneous with Langquaid type axes (late Early Bronze Age). Hence it would come as no surprise if an approach to forging, that first developed in the group of bronze Saxon axes and won widespread acceptance with the Langquaid ones, had lived on in the axes assembled in our Bronze Age horizon 2.

7.5 Deconstructing Compositional Determinism: The 'Evolution' of Material Properties?

In many discussions on early metallurgy there are interpretative problems with the notion of technological 'progress' and increasingly better control obtained over nature. The early evidence for copper mining, smelting and working is discussed in terms of 'evolution', and the succession of different types of copper and copper alloys is interpreted as an improvement in operational and functional terms. Some of the issues involved have already been raised in previous sections. In this chapter some aspects of this broad picture are taken up again to deconstruct and challenge evolutionist assumptions in commonly held perceptions of early metallurgy. It will become clear that previously clear-cut technological stages tend to become blurred, and we should not rely on evolutionist notions and/or geological conditions as a guide to the development and 'progress' of metallurgy. Cognitive aspects of early metallurgy – knowledge gained by prehistoric metalworkers of the raw materials they were working, choice beyond mere functional improvement and subtle changes through time to traditional practice – must not be neglected in favour of an approach focusing on composition and straightforward 'progress'.

7.5.1 The Influence of Composition on Casting Properties

Turning back to the first step in metalworking, namely casting, it has been argued that along the sequence from pure



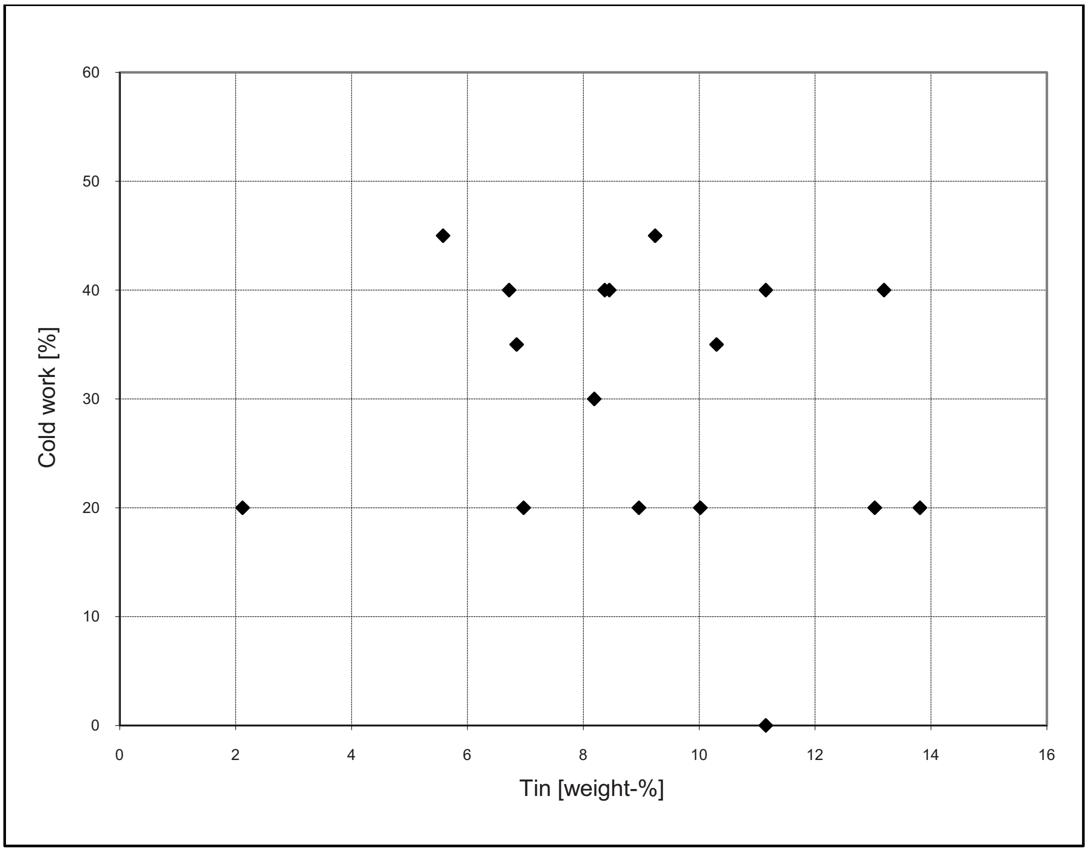


Fig. 7.32: Above: The hardness of the Bronze Age horizon 2 axes (late EBA to MBA/LBA palstaves etc.), depending on composition and cold work. Below: Strength of final cold work in this younger group of axes (cold work: % reduction in thickness).

copper via arsenical copper to fahlore copper and tin bronze the presence of trace elements and the addition of tin allows for a reduction of the casting temperature (e. g. Spindler 1971, 199; Hauptmann/Weisgerber 1985, 30; Pernicka 1998, 135; Northover 1998, 117; O'Brien 1999, 34, 40; Junk 2003, 20; Krause 2003, 207; Schwenzer 2004, 203). This is the first in a series of modernist assumptions related to the properties of different types of copper and copper alloys used in prehistory (cf. Kienlin 2008a, 251–280), and it is easily refuted by a look at the actual evidence: Copper containing 'impurities' such as arsenic or tin solidifies over a wider temperature range between the so-called liquidus and solidus lines of the phase diagram. However, for this interval to drop significantly below the melting point of pure copper (1084 °C) impurity contents in the plus 10 % range are required (for arsenic and tin see phase diagrams in Scott 1991 or Schumann 1991). Such concentrations are rarely found in Eneolithic/Copper Age arsenical copper, and most of the earliest bronzes in our area (as opposed, for example, to Britain and Ireland; Needham et al. 1989; Pare 2000) remain well below 10 % tin. Hence during the early stages of metallurgy, composition would have had little effect on casting temperature in the way suggested in many reviews of early metalworking (cf. Pernicka 1990, 48; Ottaway 1994, 130, 138–140). Moreover, metallographic data show that even with higher trace-element contents in Early Bronze Age fahlore copper (with a combination of arsenic, antimony, silver and nickel) and the advent of high-tin bronze in the second half of the Early Bronze Age casting temperature did not drop. There are copper sulphide inclusions in many of the axes examined that solidified at around 1100 °C and provide evidence that casting still took place at high temperatures (see chapter 7.2; Lesniak 1991; Kienlin 2008a, 133–136).

A related point concerns the supposed effect of impurities such as arsenic and the alloying element tin on porosity and oxide content (e. g. Charles 1967, 21; Spindler 1971, 199; Sangmeister 1971, 109, 123; McKerrell/Tylecote 1972, 209; Coghlan 1975, 81; Schubert 1981, 447–448; Hauptmann/Weisgerber 1985, 30; Penhallurick 1986, 4–5; Strahm 1994, 12; Northover 1998, 117–118; O'Brien 1999, 33–34; Junk 2003, 21–22; Krause 2003, 207; Schwenzer 2004, 207). It is possible that the wider solidification interval of impure or alloyed copper facilitated the casting of more complex objects because part of the molten copper remained liquid somewhat longer, and a complete fill of the casting mould was more easily achieved. This may apply, for example, to some Early Bronze Age pins and solid-hilted daggers (Schwenzer 2004). A differentiated approach to the production of different kinds of ornaments and weapons or tools is required. This is not, however, an argument in favour of tin bronze alone, since much Early Bronze Age fahlore copper would have offered the same advantage (Lesniak 1991, 165–166; see also Lechtman 1998, 85–87). Furthermore, complex objects are also known in rather pure copper. From the metallographic examination of Eneolithic/Copper Age and Bronze Age weapons and tools, for example, it is quite obvious, that not only comparatively simple flat axes and flanged axes but also complex shapes such as the shaft-hole implements could be cast to a high standard using pure copper. There was certainly porosity after casting, but it was reduced by subsequent forging and did not necessarily result in frequent breakage. On a related issue, it was shown above that there is no clear correlation of composition (arsenic content) and oxide frequency or type. Initially, 'poor' casting quality in terms of the ($Cu+Cu_2O$)-eutectic present in earlier Eneolithic/Copper Age axes provided additional strength and improved hardness. Later on, there was still a high amount (in modern terms) of mixed copper and copper-arsenic oxides. But these were plastically deformed, and at no stage oxides appear to have caused problems due to brittleness and breakage. Of course, we do not know the relative numbers of spoilt casts in relation to composition. Slightly better casting properties may have mattered in the production of more complex shapes as outlined above. However, in a wider perspective it is likely that the success of casting was not dependent on composition alone, but upon the care taken and the expertise acquired in various steps of the casting process.

7.5.2 The Influence of Composition on Workability and Hardness

As far as weapons and tools are concerned, during the Eneolithic/Copper Age and Bronze Age it is likely that advantages of new types of copper and copper alloys would have been most obvious and most readily taken up in the wider field of mechanical properties. But again, we must be wary of transferring our knowledge derived from a reading of modern materials science to traditional prehistoric metalworking. We have to differentiate carefully the various mechanisms involved, and consider the actual composition of the prehistoric artefacts in question.

Solid solution hardening and work hardening are examples of different properties often conflated when a new alloy such as tin bronze is claimed to be superior to, i. e. harder than, its forerunner. Solid solution hardening occurs whenever atoms of a trace or alloying element are present in the copper matrix. It confers additional hardness and strength in the as-cast or recrystallised state. Work hardening, on the other hand, requires a deformation below recrystallisation temperature (i. e. cold work), and depending on composition it may result in a considerable increase in hardness compared to the as-cast state (Schumann 1991; Kienlin 2008a, appendix I). Both processes have been claimed as an advantage of arsenical copper and tin bronze over pure copper, though often they have been confused and considered together (e. g. Charles 1967, 24; Spindler 1971, 199; Sangmeister 1971, 109, 123; McKerrell/Tylecote 1972, 209; Coghlan 1975, 80; Schubert 1981, 447–448; Hauptmann/Weisgerber 1985, 30–31; Northover 1989, 113–114; Budd/Ottaway 1991, 138–139; Strahm 1994, 12; Lechtman 1996, 502–506; Pernicka 1998, 135; O'Brien 1999, 33; Krause 2003, 207; Schwenzer 2004, 203–204).

The presence of arsenic and somewhat more so of tin does

increase the as-cast hardness of the resulting (natural or artificial) copper alloy. But with arsenic contents up to around 3 % to 4 % this effect is limited (~ 60–70 HV), and even for tin contents of around 10 % are required for an increase in hardness to twice the value of pure copper at 50 HV (Lechtman 1996). A minor increase in hardness and strength at lower concentrations may or may not have been noticed. It may have been relevant in the production of copper objects such as ornaments, that could not be cold worked or whenever mechanical properties were of little interest. In the case of ornaments (or prestigious weaponry etc.) colour also has to be taken into consideration to account for the presence of trace and alloying elements. However, for all proper weapons and tools it is unlikely that Bronze Age metalworkers should have relied on manipulating as-cast hardness via composition. The application of heat (annealing) to restore deformability and hence the knowledge of work hardening goes back to the Early Neolithic working of native copper (e. g. Pernicka 1990, 28–31). In our Eneolithic/Copper Age horizon 1 a different mechanism was involved with hardness provided by the ($Cu+Cu_2O$)-eutectic. But the metallographic data clearly show that thereafter – at least well into the Bronze Age – hardness was a function of (composition and) at times substantial cold working (see above). As-cast hardness (i. e. solid solution hardening) was certainly a concept familiar to the metalworkers themselves in this period. But whenever an axe etc. entered the sphere of exchange and use, its mechanical properties were determined by previous cold working. They would have been attributed to the effort involved in forging and the expertise of the smith. This in itself is the result of technological choices. In an Únětice context, in particular, it cross-cuts an alternative emphasis on casting ornaments etc. that were not to be forged, that might as well have invited attempts to rely on composition and as-cast hardness for weapons and implements too.

If hardness was a function of cold work, in this respect composition is also thought to play an important role. Different types of copper and copper alloys are aligned in terms of progress and improvement because of (assumed) differences in deformability and work hardening of arsenical copper and tin bronze in particular (for references see above). These differences, however, are comparatively slight when compared in the light of more recent experimental data (e. g. Buchwald/Leisner 1990, 73 fig. 20; Northover 1989, 113–114 figs. 13.3, 13.4 and 13.5; Budd/Ottaway 1991, 140 figs. 4 and 5; Lechtman 1996, 488, 494–496 figs. 18, 19 and 20; Junk 2003, 156 fig. 7.26; Kienlin 2008a, 263–264 figs. 54 and 55). Often they occur under circumstances not directly relevant to prehistoric metalworking. Arsenical copper, for example, is clearly more ductile than pure copper, and it can be worked to a very high reduction in thickness and a considerable increase in hardness. Bronze may achieve even higher hardness values, but this requires tin concentrations in excess of 10 % not reached in a majority of early tin bronzes in our area. In addition, unrealistically high deformation rates are involved from an Eneolithic/Copper Age or Bronze Age perspective. The metallographic analyses show that cold work typically was in the 20 % to 50 % range of reduction in thickness (see above). Working was not done with the highest possible hardness of the respective copper or copper alloy in mind. Rather, it was carried out to profit from the strong initial increase in hardness at lower deformation, which for different concentrations of arsenic and tin is very similar. Because of their initially close mechanical properties, under prehistoric levels of cold working arsenical copper and tin bronzes reached comparable hardness values. For the same reason the alleged brittleness of copper compared with arsenical copper or tin bronze may not have been as relevant as modern expectations have us believe. Irrespective of composition, working simply was not strong enough to cause intolerable embrittlement. Annealing took place relatively early to restore deformability and facilitate final shaping. Subsequent forging aimed to improve mechanical properties, but it very much relied on the initial increase in hardness during the early stages of deformation involved.

7.5.3 Conclusions: Composition and the 'Evolution' of Material Properties

The development of Eneolithic to Bronze Age metallurgy, which besides the casting and working technique also comprises the exploitation of new ore deposits and the formation of cross-regional exchange networks, is often depicted in terms of 'intensification' and 'improvement'. However, it would be a mistake to view the development of (Early) Bronze Age metallurgy as a process that was consciously driven forward, as a phase of rapid and inescapable progress. This was demonstrated by reference to widely held assumptions about the properties of different sorts of copper and alloys, that assume a general superiority of the respective new material and its conscious use for this reason. Evolutionist expectations regarding the nature and the inevitability of technological progress need to be revised. For casting temperature, casting properties and mechanical properties it can be shown that with the relevant concentrations either no significant differences exist between copper, arsenical copper, fahlore metal and tin bronze, or that possible advantages affected the manufacture of different object groups only to a very different extent. Statements about the workability of the raw material and properties of the finished objects should at the very least be differentiated according to whether the manufacture of weapons and tools is intended, or whether it is the form that is important (e. g. ornaments). With regard to the weighting of these factors, it should be stressed that quite naturally more elaborated forms such as solid-hilted daggers or halberds particularly capture our attention. However, the actual impact of metallurgy upon the society in question is more discernible from the production and spread of more everyday groups of objects such as the axes. For these it can be established that the composition was hardly a decisive factor of a successful casting procedure. Furthermore, there is no reason to expect that tin bronze as far as casting technique is concerned formed a prerequisite for the differentiation of artefact forms in the course of the Early Bronze Age (especially in the Únětice culture);

similar casting properties are shown by the widespread fahlore copper.

As far as the axes are concerned, it is obvious that their manufacture was orientated towards good performance during use. What is seen – from the casting to the forging – is the high competence of their creators, and over time a further cross-regional standardisation of the procedure. In this regard, with the initial juxtaposition of fahlore copper and low tin bronze, different options were available at first: Due to their specific fahlore type combination of antimony, arsenic, nickel and silver etc. at least some axes of the Salez type reached hardness values above 200 HV. The same holds true for some axes of the Saxon type with higher trace element content (> 6%), which at high reduction in thickness achieve a hardness similar to that of the majority of the axes of the Langquaid type. It is obvious, therefore, that the main difference between working fahlore type metal and tin bronze does not reside in the highest hardness reached, but in the ability to achieve high values on a regular basis. Fahlore metal requires trace element contents above 6 % to 7 % to achieve hardness values above 200 HV by cold working (a different process is involved with the axes of Sennwald-Salez, see above). On the whole, this is rare among the axes of the Salez and Saxon types and even more so for Neyruz type axes and related forms. Quite obviously it was difficult to obtain from specific ore deposits. Bronze at the required concentrations of tin, on the other hand, following a phase of transition during which access to tin was restricted and lower tin contents made its advantages less obvious (Neyruz and Saxon types), became generally available. It is this point we encounter with the axes of the Langquaid type. From the perspective of material properties, there is little that is inevitable about the succession of different copper sorts and tin alloying. In the end, tin bronze won general acceptance less because of its superior material properties, but rather due to a series of factors, especially the long-term poorer access to equivalent fahlore copper.

From the perspective advocated there remains little of the various functional reasons given for the inherent superiority of ever new sorts of copper and, eventually, tin bronze: among them their lower casting temperature, their better casting properties and their higher hardness both in the as-cast state and after working. Often such arguments neglect the actual compositions used or the approach to forging taken. There are strong evolutionist notions involved in our conception of technological progress and the interpretation of changing compositional patterns. Thus, early low-tin bronzes tend to be seen as a result of poor initial control over the alloying process or problems with access to tin, but the overall direction is perceived as given an directed towards high-tin bronze. This is only true in retrospect, and whereever arsenical or rather fahlore copper was in widespread use there was a serious alternative to tin bronze. We need to be aware of such situations, and expect contingency and possible distortions in the ‘upturn’ of metallurgy.

8
The Axes in Context II: A Case Study from the North Alpine Region of Central Europe

Early Bronze Age metallurgy in central Europe is characterised not only by the incipient use of tin bronze but by a shift in copper production from oxide ores to sulphidic ones that yielded a variety of new copper types. This copper, often rich in trace elements such as antimony, arsenic, silver and nickel, replaced the pure copper or arsenical copper in use during the Late Neolithic/Eneolithic. In fact, this development pre-dates the knowledge of alloying with tin. The earliest evidence for the occasional use of sulphidic copper ore comes from Neolithic contexts (possibly Münchshöfen: Bartelheim et al. 2002; Corded Ware/Bell Beaker: Krause 2003, 153–157). In the first half of the Early Bronze Age (EBA A1) copper derived from such sulphidic ore sources was in common use. Its effect on the production of weapons and implements has been discussed above in relation to Salez and Saxon type axes of eastern central Europe and the north alpine region (see chapters 7.3 and 7.4.1). Tin bronze, on the other hand, was initially rare and only became the standard alloy in the second half of the Early Bronze Age after c. 1900/1800 BC (EBA A2; Pernicka 1998; Pare 2000; Krause 2003, 213–224). The consequences of this development for the production of copper implements have been discussed by reference to metallographic data of Saxon and Langquaid type axes in particular (see chapters 7.4.1 and 7.4.2).

In the broadest terms, this sequence reflects a number of underlying patterns; the structure of ore deposits with oxide ores on top and sulphidic ones underneath; the development of smelting technique, with a two-step process supposedly required for sulphidic ores (however, see qualifications discussed in chapters 2.4 and 6.2); and the necessity to establish exchange networks for tin, which in this period was either derived from the German or Slovakian ore mountains or was imported from outside central Europe such as from south-western Britain or south-western to central Asia (Pernicka 1990; Ottaway 1994; Bachmann 2003; Bourgarit et al. 2003; Bourgarit 2007; Hauptmann 2007; 2008; Cierny/Stöllner/Weisgerber 2005).

Analytical work was done on the origin of the copper and the mining districts likely to have been exploited during the Bronze Age with contradictory results. H. Otto and W. Witter (1952), for example, drew attention to the so-called fahlore type copper, their *Leitlegierungsgruppe* IV, which they claimed was mined in the German *Erzgebirge* and low mountain ranges such as the Mansfeld or Northern Hassian ore-fields and then distributed widely throughout Bronze Age central Europe. A comparable approach relating copper objects and ore deposits was conducted by R. Pittioni (1957) and E. Preuschen (1967; Preuschen/Pittioni 1937). In their case, however, it was the Bronze Age exploitation of east alpine copper sources, especially in the Mitterberg area, which they thought could be proven.

A substantial increase in the number of analyses, still mainly on the artefact side, was subsequently achieved by the SAM-project (Junghans/Sangmeister/Schröder 1960; 1968). This project was somewhat more careful in the question of relating artefacts to specific mining areas. The collaborators relied on the mapping of different types of copper based on the assumption that spatial patterning would emerge and hint towards the origin of the copper types used in the Neolithic and Bronze Age periods. For the central European Early Bronze Age copper, two large groups of fahlore metal were distinguished according to whether nickel is present among the characteristic trace elements or not, and the differences in their distributions were noted. In the debate that followed the nickel-containing variant was named *Singen* copper after the eponymous EBA A1 cemetery close to the western part of Lake Constance which produced numerous artefacts consisting of this type of (mostly unalloyed) fahlore copper (Waterbolk/Butler 1965). It is this copper we encountered in our discussion of Salez type axes (see chapter 7.3). Fahlore copper with little or no nickel, on the other hand, was frequently found in neck rings *(Ösenringe)* and rib ingots (*Spangenbarren*) from large hoards in Bavaria and further east. It became known under the name of *Ösenringkupfer* (Butler 1978).

Singen type fahlore copper in its broadest definition has a wide distribution from the western Alps to the Baltic Sea as well as into the Carpathian Basin to the east (fig. 8.1). It was only in the 1990s with a statistical re-evaluation of the older SAM-groups and an increasing number of analyses from eastern central Europe that it became possible to differentiate truly north alpine Singen copper from similar fahlore type copper that was circulating in the Únětice culture area. Such copper was used, for example, in the production of the Saxon type axes examined above (see

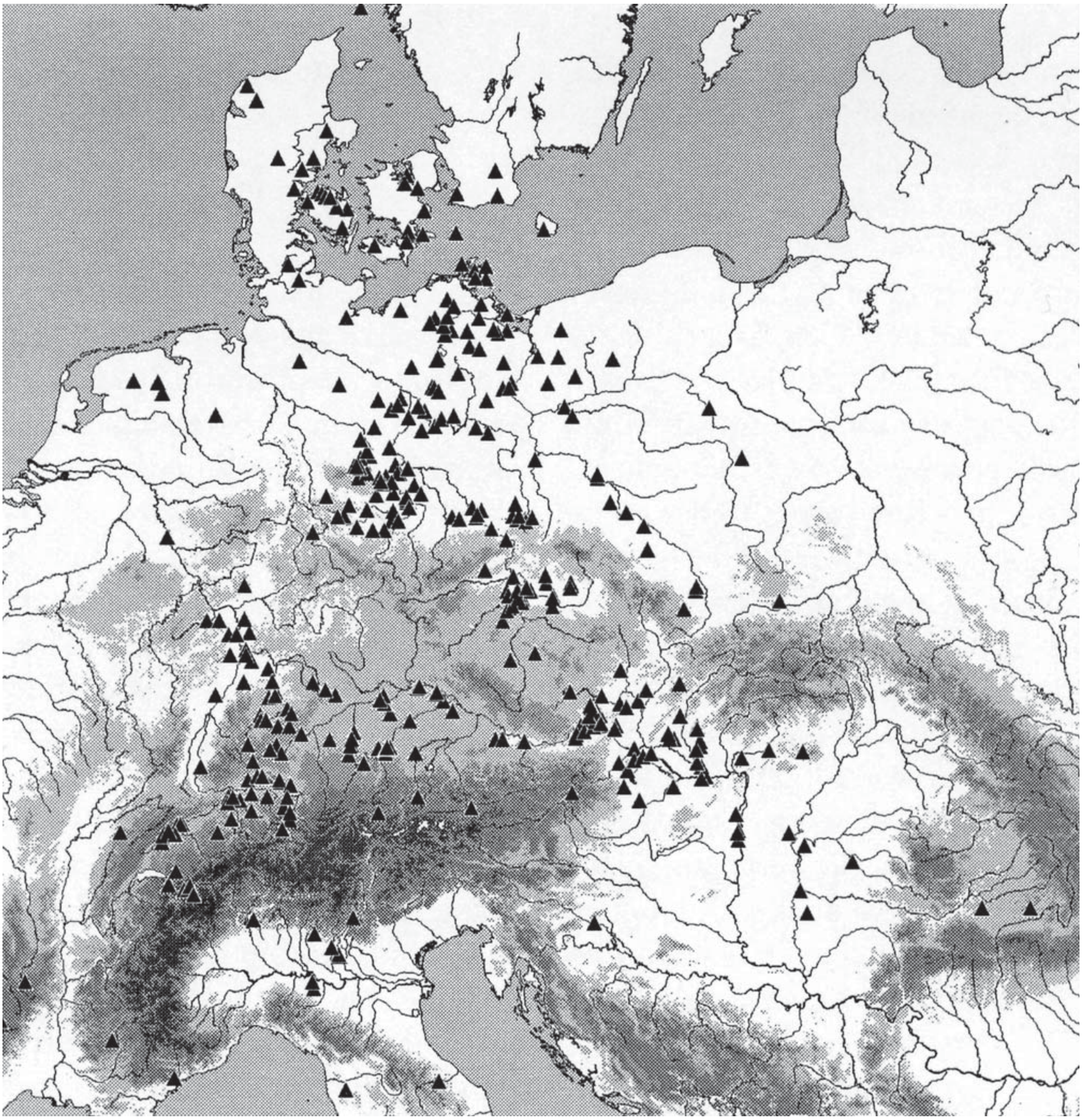


Fig. 8.1: Distribution of Singen type fahlore copper (after Krause 2003, 158 fig. 124).

chapter 7.4.1). It became clear from the work of R. Krause (2003, 122, 157–160) and K. Rassmann (2005) that we are dealing with closely related copper types with a widespread distribution in Early Bronze Age central Europe. They originated probably from the exploitation of similar ore deposits in different mining areas and by the use of a comparable smelting technique. However, systematic work on ore deposits was neglected, and we still lack sufficient chemical and lead isotope data from the alpine deposits as well as from the German and Slovakian ore mountains. Attempts at provenancing the different types of fahlore copper mentioned may therefore be seen as an informed guess based mainly on the distribution of various types of copper artefacts (e. g. Menke 1978/79; see, however, recent studies for example by Weisgerber/Goldenberg 2004; Höppner et al. 2005; Schreiner 2007; see also papers in Oeggl/Prast 2009).

Much the same is true for the organisation of copper mining and the distribution of copper, which are often modelled along modernist notions of managerial elites, craft specialisation and trade in valuable or prestigeous copper objects. The Salez type axes, in particular, feature prominently in this discussion since by their distribution along the alpine Rhine valley they provide a useful link between supposed ore deposits and the consumption of copper by communities of the pre-alpine region further north. In the following sections, therefore, these axes are contextualised by reviewing their role in current models of alpine copper production and exchange. Based on

the metallographic data presented above aspects of their function and meaning are examined. The question of the role of metal artefacts in prehistoric society is addressed, and an alternative model of Early Bronze Age mining and exchange in the area in question is developed by reference to contemporaneous settlements and graves as well as to anthropological approaches to mining, metalworking and society. However, before entering this discussion it may be useful to recall some of the above findings and pinpoint some of the controversial issues in current debates.

The apparent interest in good mechanical properties proven by metallography shows that a long use-life of the axes in practical activities was anticipated. Externally visible wear marks and signs of use in the microstructures are testimony to this. Usage as weaponry cannot be ruled out, and a clear separation of 'weapons' and 'tools' certainly does not reflect prehistoric reality. Yet the general impression is that the axes were predominantly used in situations that cannot be adequately categorised as 'conflict' or 'aggression'. The emphasis during their manufacture on good mechanical properties and the evidence of frequent re-sharpening, which resulted in an asymmetry of a large number of the axes' blades (Kienlin/Ottaway 1998), suggest that they were multi-purpose implements. As such they may have been part of (male) habitus (e. g. their occasional occurrence in graves; Kienlin 2008a, 293–312). It is apparent that they were not typically expected to be re-cast into other objects before they were beyond 'repair' by re-sharpening.

In some current models, however, these aspects are denied, and the axes are interpreted as ingots produced for the circulation of copper. Rough axe-ingots, it is thought, were circulating that were meant to be re-cast and only occasionally forged by an 'end-consumer' to turn them into proper implements (Krause 1988). A related concern of recent years is with 'money', i. e. copper axes produced primarily for the use and exchange in economically motivated contexts. To this end reference is made to the work of M. Lenerz-de Wilde (1995), who tried to establish the existence of an Early Bronze Age (proto-) currency or even money in the north alpine region. Comparably, on the southern side of the Alps M. Pearce (2007, 88–97) recently argued for ponderal systems in the Italian (later) Bronze Age and an even earlier commodification of flanged axes as *aes formatum*. The evidence from the north alpine region will be discussed in greater detail below, but here may be the right place to indicate why much of this modelling is thought inadequate – both on factual and theoretical grounds. Evidence in favour of Pearce's (2007, 86–88) view that flanged axes were some kind of proto-currency comes from the hoard of Pieve Albignola (Pearce 2007, 87 fig. 6.2) in which there are some unfinished axes of unalloyed copper (interpreted as ingots) alongside finished ones high in tin. In the north alpine region there is no such find. Metallographic data show that with a strong final cold work the axes' manufacture was orientated towards good mechanical properties, i. e. use. There is no evidence for the existence let alone the circulation of rough unfinished axe ingots. In Italy, too, such finds are an exception, and flanged axes of this kind were made from both copper and tin bronze over an extended period of time. Therefore, it might just be by chance that the unfinished axes (perhaps casting rejects) were unalloyed.

Pearce then turns to a standardisation of artefact size and shape as further evidence of *aes formatum*, arguing for "an ingot that acquired its value not by its weight but by its form, and thus visibly sufficient metal for the manufacture of a given artefact" (Pearce 2007, 91). At this point we have to carefully differentiate different lines of argument: Firstly, arguing by weight instead of size measurements, Lenerz-de Wilde (1995, 229–232, 314–321) came to the opposite conclusion that the axes unlike, for example, ingot torques *(Ösenringe)* should not be seen as currency or money. A valid definition of *aes formatum* and the methods to identify it in the archaeological record are still missing. Secondly, Pearce (2007, 92–97) shows that in the production of flanged axes a high degree of standardisation was achieved. This surely hints at the sophistication of metalworking, attention paid to the production of the axes and 'value' in its widest sense attached to them. But is this enough to establish a (proto-) currency when at the same time standardisation is seen as related to "the hafting of the axes and the dimensions of their cutting edge" and to "strictly utilitarian concerns" (Pearce 2007, 93; see also Hansen 1994, 376–379 for a related point on the standardisation of *Ösenringe*)?

Finally, we clearly touch upon differences in worldview here which cannot easily be resolved. But they certainly require discussion and a clear statement of our point of view. Interpretations of the axes as ingots or as a form of money – from an anthropological perspective – belong to a formalist school of thought that transfers modern, economical concepts to prehistoric societies (cf. Dalton 1961; 1965; 1969; 1981; Appadurai 1986; Jensen 1992; Gregory 2002; Feest 2003). On the production side this involves agreement that technological choices were governed by 'rational' considerations in a modern sense. Instead, we may want to consider that technological understanding in prehistory was fundamentally different from our own. With regard to the circulation of metal artefacts, a corresponding line has to be drawn. Do we want to opt for an economic approach focusing on the commodification of copper objects and their possible function as (proto-) currency or ingots? Or should we take a 'primitivist' stance with an emphasis on social reproduction via the circulation of copper objects and other 'valuables'?

The axes are among the most massive copper artefacts of the Early Bronze Age. So quite obviously they were re-cast, and their exchange in some way contributed to the circulation of metal. But they were not produced to this end (at least north of the Alps), and they should not therefore be regarded as ingots. M. Pearce (2007, 97) cautions us that an axe was "a carrier of real as well as symbolic value". One certainly has to agree on the implication of this line that we must not conceptualise the (Early) Bronze Age as some form of highly ritualised prestige goods system

derived from anthropology (see also Kuijpers 2008, 73–79). There should be equal levels of caution, however, towards an approach that has us believe in elements of a modern market economy in prehistory. The notion of 'currency' and a universally accepted value system carries implications for society as whole. Judging from the evidence of small-scale communities and segmentary organisation along kinship lines we should be wary to believe in an Early Bronze Age money-based exchange system devoid of social obligations among its participants. In the present study it is assumed that the (Early) Bronze Age use of material culture did not only follow 'rational' considerations in a modern sense, and the meaning of the axes cannot only be captured in economic terms. Presumably, in terms of their practical function the axes should be seen more as a tool than as a weapon. But even so, as a multi-purpose implement, they most likely bore references to their holder that extended across categories of the possession of weapons, tools and bars or economy into a reflection of his identity.

8.1 'Axe Ingots' and Current Models of Alpine Copper Mining and Distribution

The clearest expression of the approach challenged here was developed in several studies by R. Krause (1988; 1998; 2003; 2009) with regard to the Singen copper *sensu proper* from the north alpine region of central Europe. The starting point of his model was the eponymous cemetery of Singen excavated in the 1950s but properly published only in 1988. Singen is a typical cemetery of the north alpine Early Bronze Age with some 90 graves in four to five groups (fig. 8.2) covering the first half of the Early Bronze Age (EBA A1), in absolute terms the time from roughly 2200–2000 cal BC (Krause 1996). Grave goods include amongst others a characteristic spectrum of daggers, needles, rings and other ornaments of copper (fig. 8.3) which were analysed in two series; first by the SAM-project and subsequently by the Heidelberg laboratory (Christoforidis/Pernicka 1988).

Using this data, Krause (1988, 181–213) was able to show that while most artefacts consist of a relatively homogeneous fahlore type copper (i. e. Singen type copper) some had a different trace element signature interpreted as *Fremdmetall*. According to Krause (1988, 56–63, 212), among these there is a group of Atlantic daggers (see, however, Gallay 1991, 205; Gerloff 1993, 75–76; 2007, 124–136). A connection is drawn with tin supply from Cornwall to Singen (Krause 1988, 242–244) although in fact the vast majority of the Singen artefacts are unalloyed and therefore do not indicate the regular use of tin (see Krause 1988, 272–274). Finally, Krause (1988, 29–31, 125–130, 205–213) drew attention to systematic differences in the trace element content of various types of artefacts recovered from the Singen cemetery. With reference to the grave groups, this finding was interpreted as a chronological sequence indicating changes in metal supply through time.

Turning from Singen to its surroundings Krause (1988, 214–242) noted that Singen copper was also used in the production of Salez axes known from the region on both sides of Lake Constance and the alpine Rhine valley in the south (fig. 8.4). The identical composition to the cemetery's artefacts and their distribution extending into the Alps was taken to support the role of these axes in the trade of alpine copper. They were interpreted as ingots and their distribution was taken to reflect the spread of a specific alpine copper type mined somewhere in mining districts along the alpine valley of the river Rhine and its tributaries. The community in Singen was supposed to have occupied an important step in this so-called *Metallurgiekette* (metallurgy chain) by controlling metal trade into the area north of Lake Constance where the number of axe ingots known gradually decreases because they were supposedly remelted to cast other kinds of artefacts (Krause 1988, 219–232, 238–242). This concept, which is modelled on the eastern alpine distribution of *Ösenringe* and rib ingots (Menke 1978/79; cf. Krause 1988, 214), was also extended to flanged axes of Neyruz type whose main distribution is in the western part of Switzerland (Abels 1972, 11–14). There is no significant overlap with Salez type axes and both groups consist of different kinds of copper. This was interpreted as the result of neighbouring exchange systems for alpine copper derived from different mining regions (Krause 1988, 223–232). Furthermore, younger axes of Langquaid type, too, are thought to have played a comparable role in the exchange of copper (Krause 2003, 52).

Given the number of Singen type copper artefacts known and the existence of alpine ore deposits, it is in fact likely that Singen copper was mined somewhere in the Alps alongside the Rhine valley or further south in the central Alps of the Swiss canton Graubünden. Unlike the situation in the eastern Alps, however, there still is no conclusive evidence of Bronze Age mining in this area, and traces of the practice of metallurgy in Early Bronze Age settlements are rare (e. g. Fasnacht 1999; Krause 1988, 214–218, 238–241; 2003, 34–36, 198–199). This is why Krause in his more recent work made the important step towards settlement archaeology in potential alpine mining areas and in Bartholomäberg in the Montafon region where he began excavating an Early to Middle Bronze Age settlement (Krause 2005a; 2005b; 2007; 2009; Krause/Oeggl/Pernicka 2004; Schmidl et al. 2005). Bartholomäberg-Friaga Wald is a hilltop settlement of about 90x50 m size which in its early Middle Bronze Age phase comprised some six to eight houses built on a settlement terrace. The fairly massive stone wall built to support this terrace and an extension to it without an obvious supporting function are interpreted as a fortification (Krause 2005a, 401–407; 2007, 122–126). Bartholomäberg is therefore seen as a central place (*Burg*) controlling some smaller neighbouring sites in what is conceived of as a hierarchical settlement system (Krause 2005a, 408; 2007, 132–133). Although there is no evidence of metallurgical activities on the site (Krause 2005a, 405), it is supposed that power was derived from control over the exploitation of copper ore deposits in the vicinity and the exchange of copper (Krause 2005a, 408–409; 2007, 129–133). This stands in contrast to S. Shennan's (1995) interpretation of St. Veit-Klinglberg in the eastern Alps

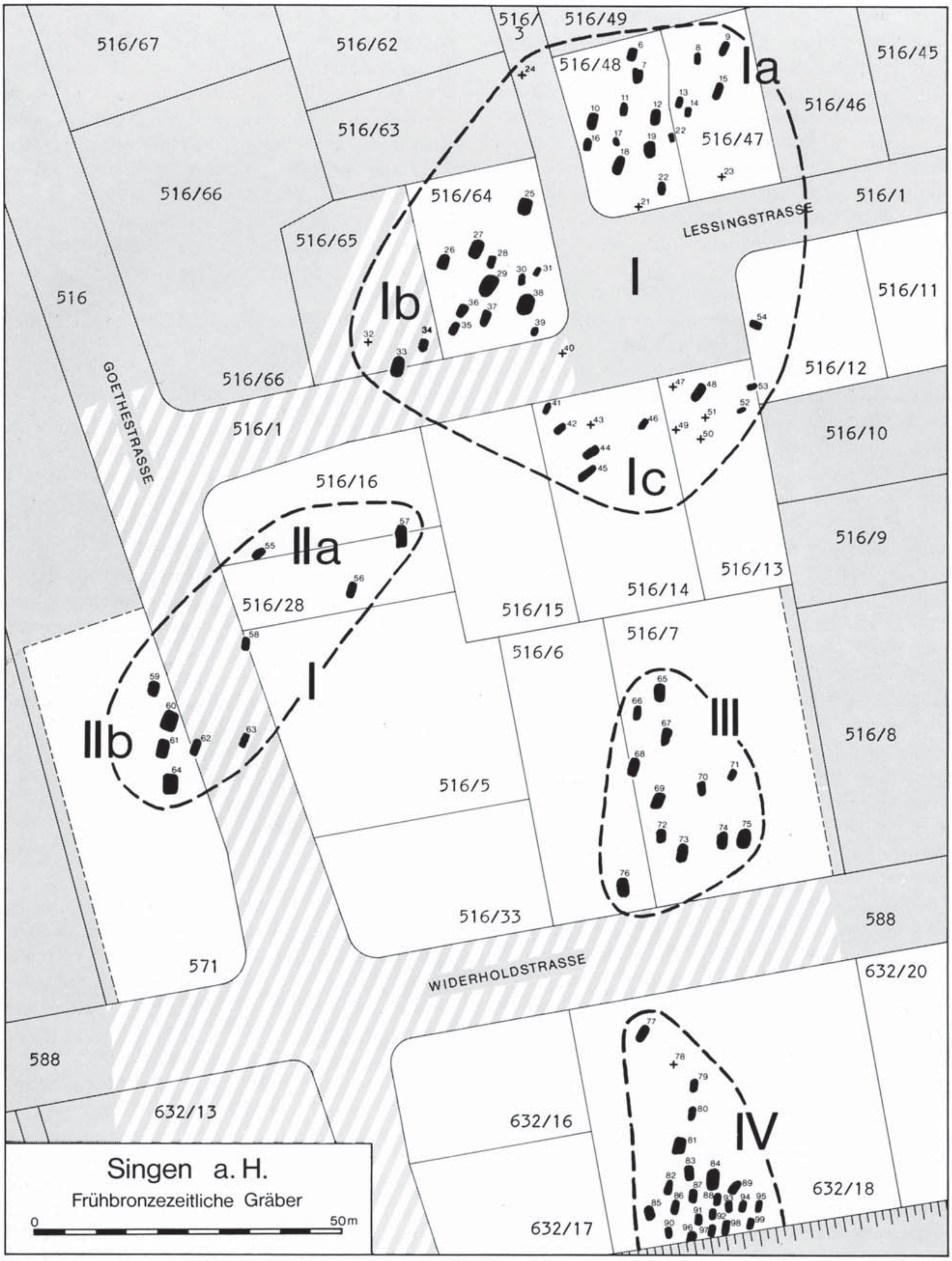


Fig. 8.2: The Early Bronze Age cemetery of Singen am Hohentwiel – grave groups (after Krause 1988, 28 fig. 6).

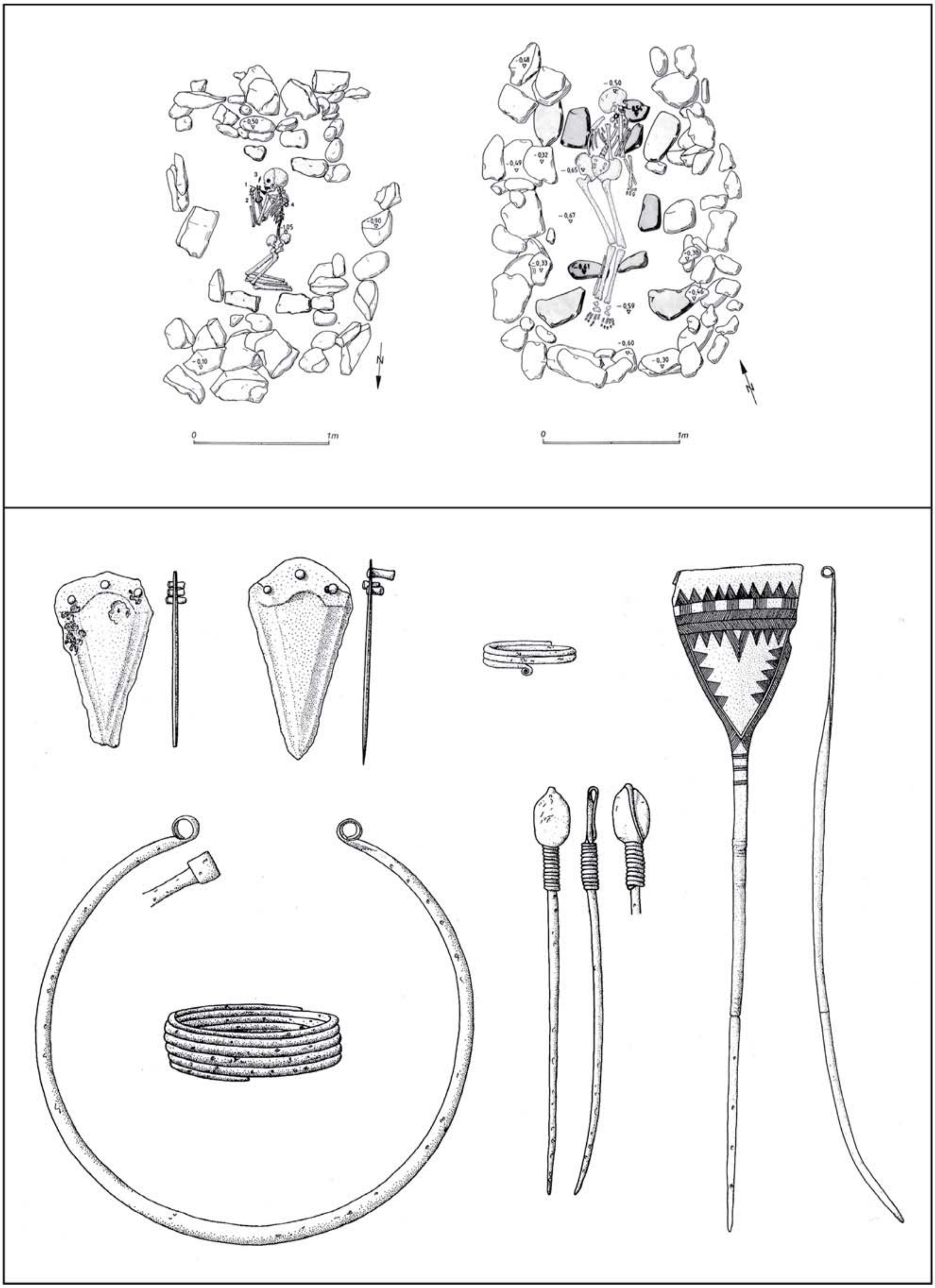


Fig. 8.3: The Early Bronze Age cemetery of Singen am Hohentwiel – crouched burials with stone settings (graves 19 and 68); typical grave goods (after Krause 1988, 50 fig. 13, 64 fig. 23, 72 fig. 31, 80 fig. 38, 86 fig. 42b, 304 fig. 128, 325 fig. 183).

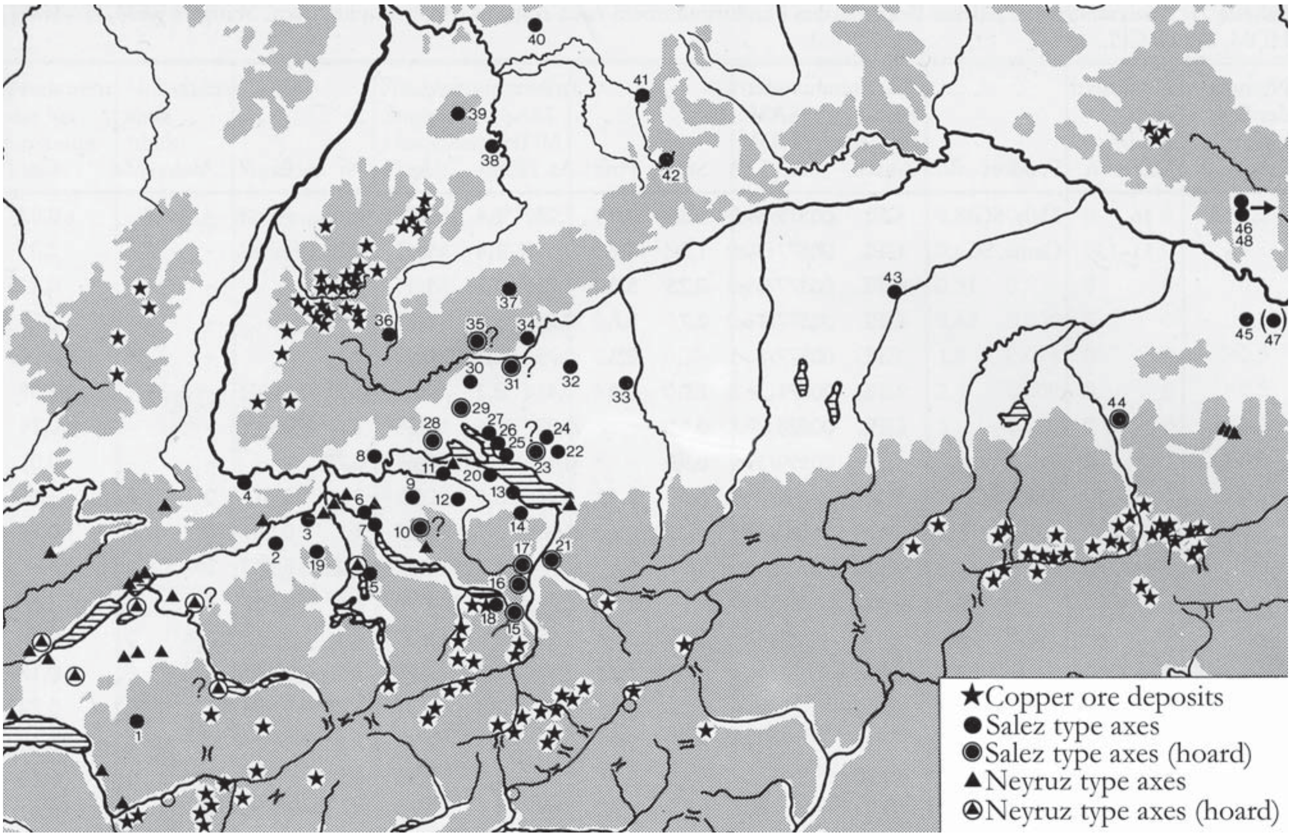


Fig. 8.4: The distribution of Salez type axes in the north alpine region (after Krause 1988, 221 fig. 93).

as a mining settlement operating largely autonomously without centralised control. Instead, Krause's model is in line for example with Ch. Strahm's (1994; 2002; Strahm/Hauptmann 2009) conception of early metallurgy, mining and the production of metal as a complex technology requiring organisation and control exercised by emerging Bronze Age elites (Krause 2005a, 391–395, 408–409; cf. Krause 2003, 257–262).

The current model of Early Bronze Age mining in the western Alps and the distribution of Singen copper into the north alpine area consists of three distinct elements. Firstly, there is the assumption that in the alpine mining districts there were local communities dominated by elites that derived their power from control over mining and metallurgy. Secondly, there is the notion that exchange in copper took the form of directional trade involving the production of ingot axes and that these were normally recast into other kinds of artefacts and only occasionally finished by forging etc., according to the needs of an 'end-user' (Krause 1988, 232, 240–242). Thirdly, there is the idea that in the lowlands there were communities able to monopolise exchange and benefit from their geographical position (in particular Singen as opposed, for example, to the poorer Adlerberg graves; Krause 1988, 138; 2003, 48–49) and that this whole system developed and remained in operation over a considerable period of time (Singen/Salez axes: EBA A1; Langquaid axes: EBA A2; Bartolomäberg/other fortified settlements in the Alps: EBA A2 to Middle Bronze Age; see Krause 2005a, 396 fig. 5, 409–410). All this is based on the assumption that the most important reason for the colonisation of the Alps was copper. The economic background of the move into the Alps was the emergence of a copper industry that supplied copper to the north alpine region around Lake Constance or the Inn and Salzach valleys.

8.2 Alternative Approaches to Mining and Metal Production

There are problems with a number of aspects of the current model, which will be dealt with in the following paragraphs. Generally speaking, there is a tendency to see the European Bronze Age as a historically unique development. Consequently, Bronze Age society and – for our present purpose – the organisation of its metallurgical activities is conceptualised as somehow distinct from both what anthropology tells us about technology in traditional societies and the evidence from earlier Neolithic societies. Mining and metallurgy are seen as an exceedingly complex undertaking discussed in the context of emerging social hierarchies. However, large-scale mining activities for lithic raw materials took place already in the Neolithic, and unlike Bronze Age research in Neolithic debates there is at least an explicit statement of different possible approaches, broadly reflecting the formalist versus substantivist positions outlined above.

On the one hand, there is a strong interest in technical aspects of mining, such as the methods and high competence

required to sink shafts and operate large mines, in geological aspects and the distribution of different varieties of flint or stone which are traced by archaeological means and/ or scientific methods (e. g. papers in Sieveking/Newcomer 1987; Schild/Sulgostowska 1997; Weisgerber/Slotta/ Weiner 1999; Körlin/Weisgerber 2006). This approach often is accompanied by modernist assumptions on the rational behaviour of highly skilled mining specialists and a formalist perspective on the economic context and social organisation of mining activities (cf. De Grooth 1997, 71; Johnston 2008, 191–192). Alternatively, however, there are studies drawing on ethnographic analogies such as the well-known New Guinean case studies to explain Neolithic mining and stone tool production (e. g. Taçon 1991; Pétrequin/Pétrequin 1993). As with discussions on craft specialisation in general (Rowlands 1971; Neipert 2006) the resulting picture is highly variable and different from modern expectations (for a similar point see Kohring/ Wynne-Jones 2007). But it is quite clear, that social elites with attached specialised miners are not a pre-condition for impressive mining workings. Rather, there is ample evidence for the ability of small-scale tribal societies to operate such activities on a consensual basis without coercive force being applied. Furthermore, mining is rarely done continuously throughout the whole year but typically is a seasonal activity carried out by a group of participants who may fluctuate from occasion to occasion and from year to year. The individual control of mining and 'ownership' of the mines are concepts that need not apply to pre-modern societies. This is an important point that applies especially to societies whose access to mineral resources was basically sporadic or seasonal. Mining may carry strong ritual connotations, and it can often be observed that ritual 'control' is interwoven with the 'care' of special resources by social groups or individuals who are seen as having close relationships with transcendental powers (e. g. Burton 1984; McBryde 1984; Torrence 1986; Pétrequin/Jeudy/Jeunesse 1993; Pétrequin/Pétrequin 1993; 2006; Pétrequin/Jeunesse 1995; Whittle 1995; Edmonds 1995; 1998; De Grooth 1995; 1997; Voytek 1997; Bisson et al. 2000; Stöllner 2003; Clark/Martin 2005; Pétrequin et al. 2005).

The ritual complexity of indigenous or traditional raw material procurement provides us with some important information (see Th. Stöllner in: Kienlin/Stöllner 2009, 73–76). First, it shows that exploitative expeditions often have a clear ritual frame in which certain members of a society act. Often the young men of a tribe have to prove their virtue and their ritual knowledge of how to interact with the transcendental powers in order to gain access to the desired source. Such gangs are regularly guided by experienced individuals who not only know the ritual ceremonies but also have the technological knowledge of how to exploit the quarries and mines. Such clan chiefs also have to negotiate access when it is necessary to pass through hostile lands and are in charge of the distribution of the yield. Large expeditions are recorded and aspects of initiation were involved the course of the journey, for example in the case of stone quarrying expeditions in Irian Jaya or in the expeditions to the quarries of Mount Hagen in Papua New Guinea. The ritual complexity is striking that may be involved in the exploitation of particular deposits that provide the raw material for objects of social or ritual significance such as bride prize axes. Even in hunter-gatherer communities or early agricultural groups we clearly have to be aware of the complex levels of organisation of such periodical expeditions and mining activities that were closely interwoven with and governed by a variety of cultural categories such as age, gender and kinship.

Participation in ritual knowledge may be a precondition to participate in mining, and its transmission to younger members of a community may be subject to the social strategies of the elders. Alliances may be involved and required if mines, as is often the case, are far from home territory meaning that access needs to be negotiated or enforced. Much the same applies to the raw materials extracted, the artefacts produced and their circulation. Rarely are these seen in purely functional terms, and seldom is their exchange governed by merely economic criteria (see also Knapp/Pigott/Herbert 1998; Topping/Lynott 2005; O'Brien 2007; Johnston 2008; Wager 2009). Instead objects may carry and convey meaning, obtain a biography of their own, and their exchange provides an opportunity to negotiate social relations and reinforce alliances.

On the other hand, practical aspects should not be neglected either since accessibility not only depends on social and ritual notions but also involves consideration of settlement, topography and spatial distance. In order to gain a better understanding of alpine copper production during the Early Bronze Age it is important, therefore, to develop a contextual approach referring back an anthropologically informed awareness of the social and ritual dimensions of traditional mining to the archaeological evidence of past groups involved in alpine copper production and taking direct or indirect favour from these exploitations (socially as well as economically). We may do so by roughly differentiating between two main modes of access to raw material deposits (see Stöllner 2003; 2008): Exploitation may either be a sporadic or seasonal undertaking, or it may involve the development of more stable settlement communities in the surroundings of the mining areas, which allows permanent subsistence strategies and a larger scale of raw material exploitation. In a long-term perspective these may be a succession, and permanent mining activities and ore exploitation have to be seen as a consequence of a series of initial steps often involving a considerable period of time. According to our current knowledge about early mining and metallurgy in the Alps, we therefore should expect permanence in mining not earlier than in phases with established subsistence economies and permanent settlements.

S. Shennan's (1992; 1993) concept of mining in society, in the context of his work on St. Veit-Klinglberg (Shennan 1995), was inspired by a formalist reaction to a specific Neo-Marxist reading of prestige goods systems and an

emphasis on elite ideologies that prevailed in parts of the British theoretical debate. One does not have to subscribe to his notion that mining offered hitherto unknown potential for individual ambition and offered ways to break through traditional social boundaries by acquiring metal and wealth. But surely in much German discussion too there is a problem with a 'myth of control' (Shennan 1993, 59). Drawing on the evidence outlined above it is argued instead that the wide variety of organisational options demonstrated in ethnography need to be taken into account when talking about Bronze Age mining and metallurgy. However, its controversial emphasis on elites and metallurgy is only one aspect in which the 'standard' model (Krause 1988; 2003) lacks support in the archaeological evidence. In what follows some of these shortcomings will be discussed, starting with the notion of directional trade in metals and the postulated existence of so-called axe ingots. Secondly, we need to ask exactly what kind of societal context and, for example, settlement or burial evidence we might expect if indeed there were elites in control of mining in the Alps and the distribution of copper to adjacent groups. On this basis, finally, a more nuanced approach to the initial stages of Early Bronze Age mining and metal production will be proposed.

8.3 Axe Ingots and Directional Trade? Modernist Conceptions in Distribution Studies of Singen Copper

Problems with the notion of Early Bronze Age axe ingots have been already noted in a previous paper (Kienlin 2006b). Objections derive from the metallographic examination of basic production parameters and the properties of the axes as well as from more general considerations about material culture in prehistoric society.

The concept of axe ingots does not deny the practical use of the Salez type axes as a weapon or tool in general. Yet it is assumed that the axes were initially produced with metal circulation in mind and intended by their shape to mark a specific type of alpine copper. As such they are supposed to have been circulated unfinished, in a roughly worked state, until some 'end-user' down the line of metal trade did not recast them, but decided instead to turn them into a proper axe by forging and grinding to achieve hardness and a sharp cutting edge (Krause 1988, 240–242). This assumption is clearly wrong in the light of the metallographic evidence presented (see chapter 7). Quite a large number of such axes were examined, and there is no evidence for the existence let alone the circulation into the lowlands of rough unfinished axe ingots (*Beilrohlinge*; Krause 1988, 232). Instead, it can be demonstrated that the axes' manufacture was orientated towards good mechanical properties. This aim was achieved by a rather intense and time-consuming process of forging and cold working for all the axe types examined (Saxon, Salez, Neyruz and Langquaid). From the stability in basic parameters of approach it is obvious that forging was not done on an occasional basis by individual 'end-users' (e. g. there are no cold worked as-cast microstructures which went unannealed, and there are systematic differences in the strength of final cold working *between* the axe types examined but no random variation within). In the Salez case we saw some flexibility in approach due to different trace element contents, yet there is no exception to the general rule. It is possible that their lighter colour added to the attractiveness of the Sennwald-Salez and Hindelwangen axes (see chapters 7.3.1 and 7.3.2). But the superior mechanical properties of this specific type of copper did not go unnoticed either and certainly caused the axes to be held in high esteem. Casting and forging took place in some kind of production context, and it is probable that this was decentralised and at least in part removed from the Alpine mining regions. While metallography testifies to intense communication of metallurgical knowledge among those segments of society actually practicing metallurgy, the many different shapes or variants of Salez type axes (Abels 1972) hint at local identities as the background to this metalworking.

A similar argument was made before by J. Bill (1997, 251) with regard to the careful polishing of most of the axes – a time-consuming surface finish which he suggested makes it unlikely that they were expected to be re-melted soon. The emphasis in manufacture clearly was on appearance and good performance during some kind of use. This certainly took the form of both aggression (weapon) and more day-to-day activities (multi-purpose tool). It is the latter that we actually find evidence of as on many axes from both the alpine region and the lowlands there are externally visible wear marks (Kienlin/Ottaway 1998) as well as signs of use in the microstructures which give testimony to prolonged practical use (Kienlin 2008a).

Since they are among the most massive copper artefacts of the time and area in question, the axes certainly were exchanged and re-cast. In this sense they contributed to the circulation of metal between Early Bronze Age settlement communities. This did not, however, involve directional trade in axe ingots. We may turn to a last category of evidence to repeat our point: Salez type axes are known from a number of hoard finds in both the alpine region and north of Lake Constance (Abels 1972). These hoards were taken by Krause (1988, 219–226) as part of his *Metallurgiekette* on the assumption that they reflect trade in alpine copper towards the Singen community and onwards towards groups depending on them for their metal supply. Now, it has been demonstrated that there were no axe ingots, and the axes in hoards in no way differ from all the rest, both in respect to their manufacture and the presence of wear traces. There are differences, however, with regard to the number and kind of objects contained in the hoards, their topographical setting and in the way the objects were buried (see Stein 1976; 1979). This is why we have to reject the idea that there is a single explanation to account for all hoards whether they were deposited by traders in metal (Krause 1988, 219–232, 242) or for religious reasons (Krause 2003, 205–206; see also Hänsel 1997). Instead there is variability in the archaeological evidence and most likely in prehistoric motivation and perception as well (e. g. Bill 1997; Kienlin 2006b). The evidence must not be rectified by reference to single causes and the transfer of

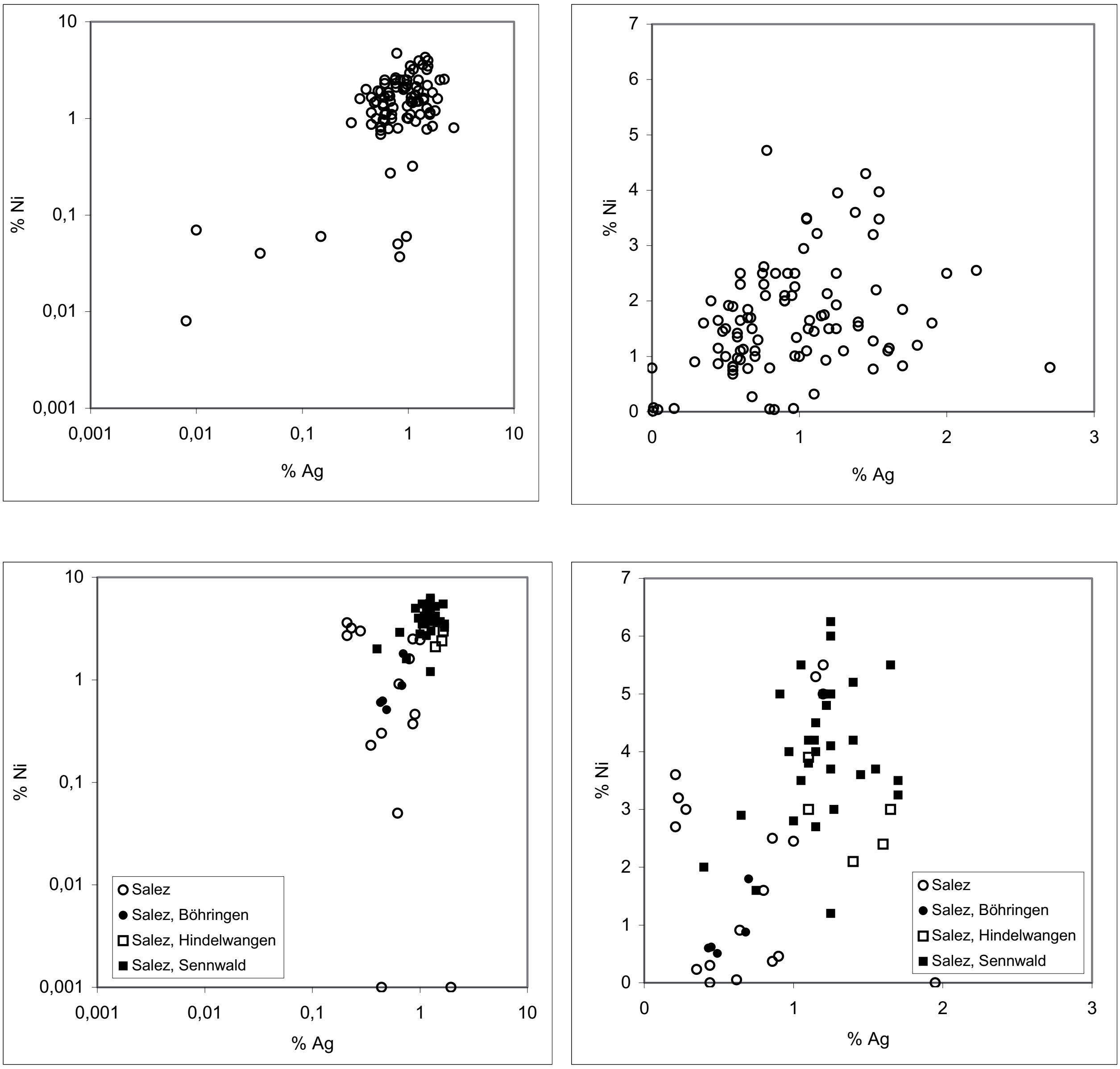


Fig. 8.5: Nickel and silver contents of the artefacts from the Singen cemetery (above) and of Salez type axes (below) – comparison of logarithmic and linear data presentation.

modern, economic concepts such as ingots or some kind of (proto-) currency to Bronze Age society. There is a tension in much Bronze Age research which, on the one hand, has us believe in rational actors controlling metal production and exchange for their material profit and the enhancement of their social standing, while on the other being stricken by superstition. Instead, we see patterning that stems from complex mechanisms of exchange and interaction among people and possibly among people and the supernatural. Beyond categories such as weapon, tool, ingot or money, the 'possession' of the axes probably was woven into socio-cultural categories of order. Their circulation should be seen in the framework of socially motivated exchange systems.

8.4 Grave Groups and Kinship: Reconsidering the Singen Evidence

Turning back to the Singen cemetery itself there are two ways to look at the analytical data – both of which were taken by R. Krause (1988). The first one emphasises similarity and leads to the definition of Singen type copper, nowadays by cluster analysis with the results illustrated by use of the logarithmic diagrams first suggested by Waterbolk/Butler (1965). The overall similarity in trace element signature is taken to imply the origin of the copper used for the Singen artefacts from a specific mining area (Krause 1988, 240). One the other hand, within the wider limits of Singen type copper defined this way there is also variation. In particular the antimony and silver contents vary and – somewhat less marked so – arsenic and nickel are present in different concentrations (Krause 1988, 207–211). With regard to the differential distribution of the artefacts in question in the Singen grave groups Krause (1988, 242) argued for a chronological sequence with changes to the trace element content of Singen copper occurring through time. Since similar variation occurs among Salez type axes,

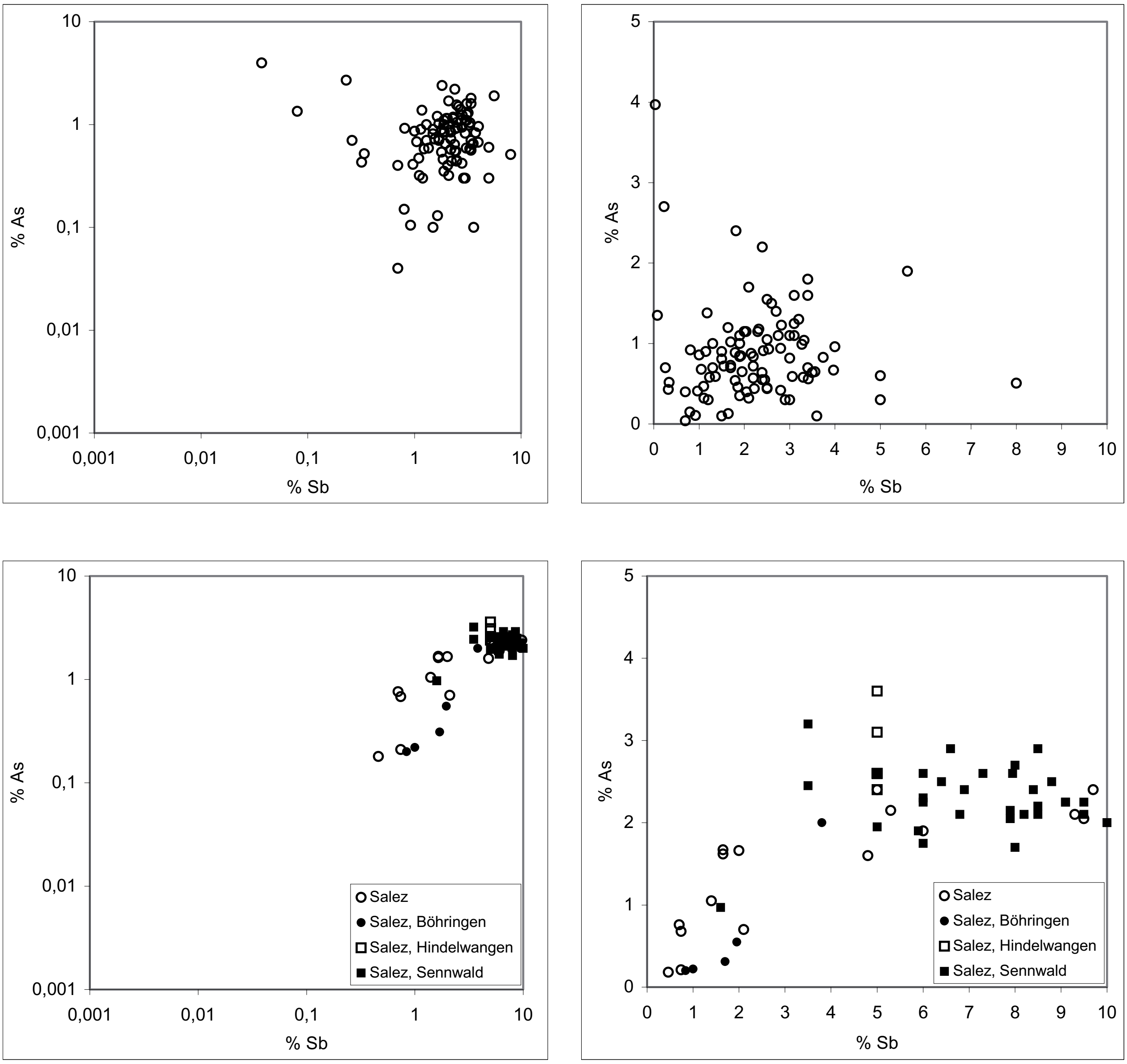


Fig. 8.6: Arsenic and antimony contents of the artefacts from the Singen cemetery (above) and of Salez type axes (below) – comparison of logarithmic and linear data presentation.

these were arranged accordingly. The hoards, in particular, were used to outline changes in metal supply to Singen as follows: the older part of Singen cemetery = Early Bronze Age A1a = Salez axes from Hindelwangen hoard; the younger part of Singen cemetery = Early Bronze Age A1b = Böhringen-Rickelshausen hoard.

This is not the place to discuss the various approaches to the statistical grouping of the analytical data applied since the 1960s. It will not be disputed that what is called Singen copper from a chemical and geological point of view is a relatively homogeneous group that apparently derives from the exploitation of comparable ore deposits. Yet it is noteworthy that the traditional way to present the analytical data by means of logarithmic diagrams (e. g. Krause 1988, 189–190) is apt to disguise variation that was most likely important to Early Bronze Age metalworkers. This is easily demonstrated if one supplements the logarithmic diagrams in common use (Krause 1988, 189–191 figs. 76–78, 225–226 figs. 94–95) with the corresponding ones in linear scale (figs. 8.5–8.7). The logarithmic scale diagrams for all three pairs of elements (Ni/Ag; As/Sb; As/Sn) give the impression that the Singen artefacts and the Salez axes consist of much the same kind of copper. The linear scale shows, however, that the actual concentration of trace elements present differs widely, and among the axes there is a group – mainly from the Sennwald-Salez and Hindelwangen hoards – which are notably higher in nickel, antimony and arsenic than most of the Singen artefacts (fig. 8.8). This finding might not be important if the only interest one takes is in the kind of copper ore deposits exploited. These were undoubtedly similar, and it is likely that a comparable smelting technique was used. However, in the above discussion of the metallographic evidence it was shown that such differences in composition did not go unnoticed and as a result the Sennwald-Salez and

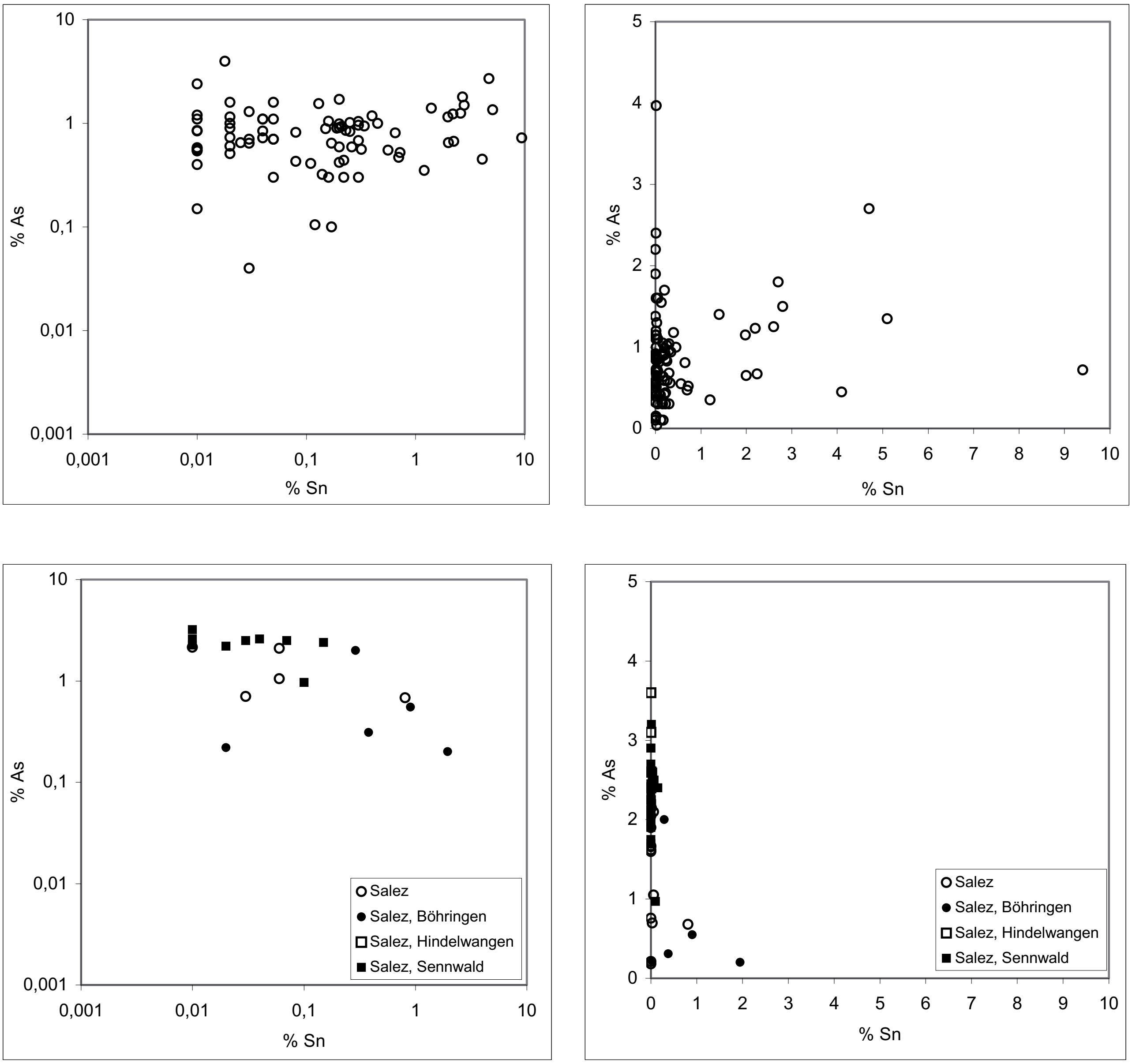


Fig. 8.7: Arsenic and tin contents of the artefacts from the Singen cemetery (above) and of Salez type axes (below) – comparison of logarithmic and linear data presentation.

Hindelwangen axes show a different approach to forging (see chapter 7.3.1). It is possible that upon repeated re-casting the loss of trace elements might eventually lead to a Singen cemetery type copper. As it is, however, the copper of Sennwald-Salez and Hindelwangen is not identical to Singen (see also Bertemes 1992; Gerloff 1993, 75; Bill 1997, 250–251) and neither is the working of it.

This adds complexity to the whole question of metal supply. For it is possible that instead of mere chronology, the compositional variation in Singen itself as well as among the axes (Böhringen-Rickelshausen vs. Sennwald-Salez and Hindelwangen) hints at small-scale, decentralised mining and smelting activities. Depending on the people involved and the ore deposits accessible to them at a specific time this might have caused the widely different results in trace element contents observed and consequent flexibility in the working of this copper. Moreover, as there are differences in workability and, for example, colour we need to be aware that the use of different types of copper may be governed by a whole range of choices beyond the immediate grasp of the archaeologist. Sennwald-Salez and Hindelwangen copper seems to have been preferred for weapons and tools because of the mechanical properties. Others might have been attracted by its conspicuous colour for ornaments, but at least as far as the Singen cemetery is concerned they obviously failed to gain access to precisely this kind of copper and/or its deposits.

Possible problems with the notion of a chronological sequence of the Singen grave groups were noted right from the start for it is unclear whether the fine-grained chronology of Bavarian grave finds (mostly needles; Ruckdeschel 1978) used by Krause (1988, 119–130) is in fact applicable to

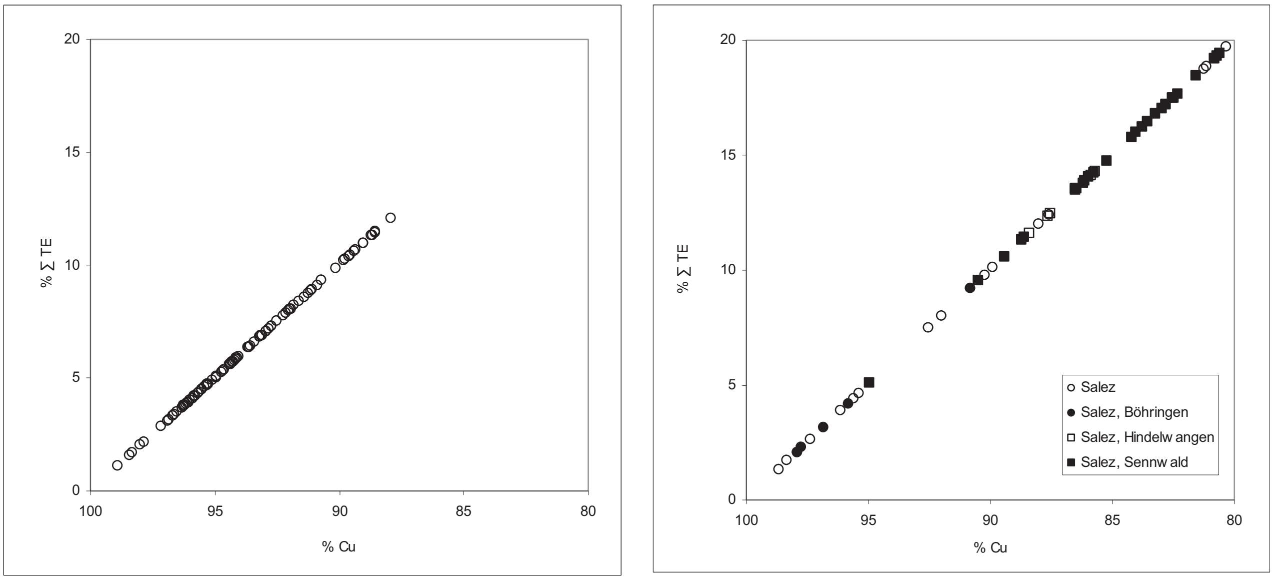


Fig. 8.8: Comparison of the trace element contents of the artefacts from the Singen cemetery (left) and of Salez type axes (right) – trace elements: sum of trace elements without tin; copper: difference to 100 %.

wider areas of the north alpine region (Schier 1991, 224–225). In a similar vein, recent discussions imply that spatial patterning in Early Bronze Age cemeteries might not be indicative of chronological differences alone but in fact refer to different settlement communities burying their dead separately in what to us appears as one large cemetery (e. g. Bartelheim 1998, 149–151; 2004 [Polepy in Bohemia]). A detailed analysis of Franzhausen I, for example, shows that the arrangement of graves into nine distinct groups was governed by a complex interplay of social and ritual aspects (fig. 8.9). There is no linear chronological sequence throughout the whole cemetery. Rather, new graves were arranged around older ones, starting from several 'cores' of slightly different ages, thereby referring to different cultural affiliation (e. g. there is stronger claim to Corded Ware tradition in one part of the cemetery) and social standing (Spatzier 2007, 238, 243–246). The whole pattern implies a small-scale segmentary structure which, in this case, is also evident from the surrounding settlements along the contemporaneous Traisen valley (fig. 8.9; strong Neolithic traditions in Early Bronze Age economy and society are also argued for, for example, with respect to the EBA settlement of Zwenkau: see Schunke 2009).

A comparable finding is reported from Mokrin, an Early Bronze Age cemetery of the Maros culture or group, which extended on the Maros and Tisza river from roughly 2500 to 1700 BC (fig. 8.10; Girić 1971; Soroceanu 1991). Where previously it was thought that there was one large community and burial developed in a unilinear pattern (e. g. Primas 1977; O'Shea 1996), recently it was shown that there are distinct rows of graves along which burial took place and developed through time (fig. 8.10; Wagner 2005). The grave goods point towards the presence of people of different traditions or identity expressed via pottery decoration and their use of metal ornaments (Wagner 2005, 132–142). Previous studies by physical anthropologists provided evidence of differences in diet between the individuals buried in these rows of graves (Rega 1997, 239). Now additional evidence comes from a study, whose authors were able to show that physical activity patterns – i. e. labour intensity and activities carried out as derived from musco-skeletal markers – do not show any clear correlation with social 'status' as determined by an archaeological analysis of the grave contents (Porčić/ Stefanović 2009).

At face value such findings clearly suggest that we are dealing with small-scale social segments such as lineages or clans. Quite obviously there was no power or authority extending beyond the immediate co-residential unit, kin group or the limits of the indiviual's lifespan (O'Shea 1996). Yet, even in the most recent studies on the basis of a meticulous analysis of grave goods slight differences in 'richness' are noted and interpreted in terms of ranking (Wagner 2005, 132–145; Porčić/Stefanović 2009, 265–267). Apart from confusing economic success and political power it is suggested that this conceals the more basic principles along which these communities were organised. In a processual tradition methodological sophistication is directed towards differential access to power and wealth, and it is only underlying evolutionist assumptions that have us believe that the patterning observed indeed refers to ranking – to the neglect of the obvious, a lineage-based, segmentary system. There is a discrepancy between the attempt to meet expectations derived from a Bronze Age master narrative, hereditary social inequality in Bronze Age chiefdoms, and the data at hand which implies that status, if any, in the male group was achieved by age and heavy labour, not just warfare (i. e. Big men or rather lineage heads). This tends to go unnoticed because the evolutionist framework in which such interpretation takes place is not reflected upon (see chapter 5.2). If this is the case and in the Singen cemetery we encounter small-scale social

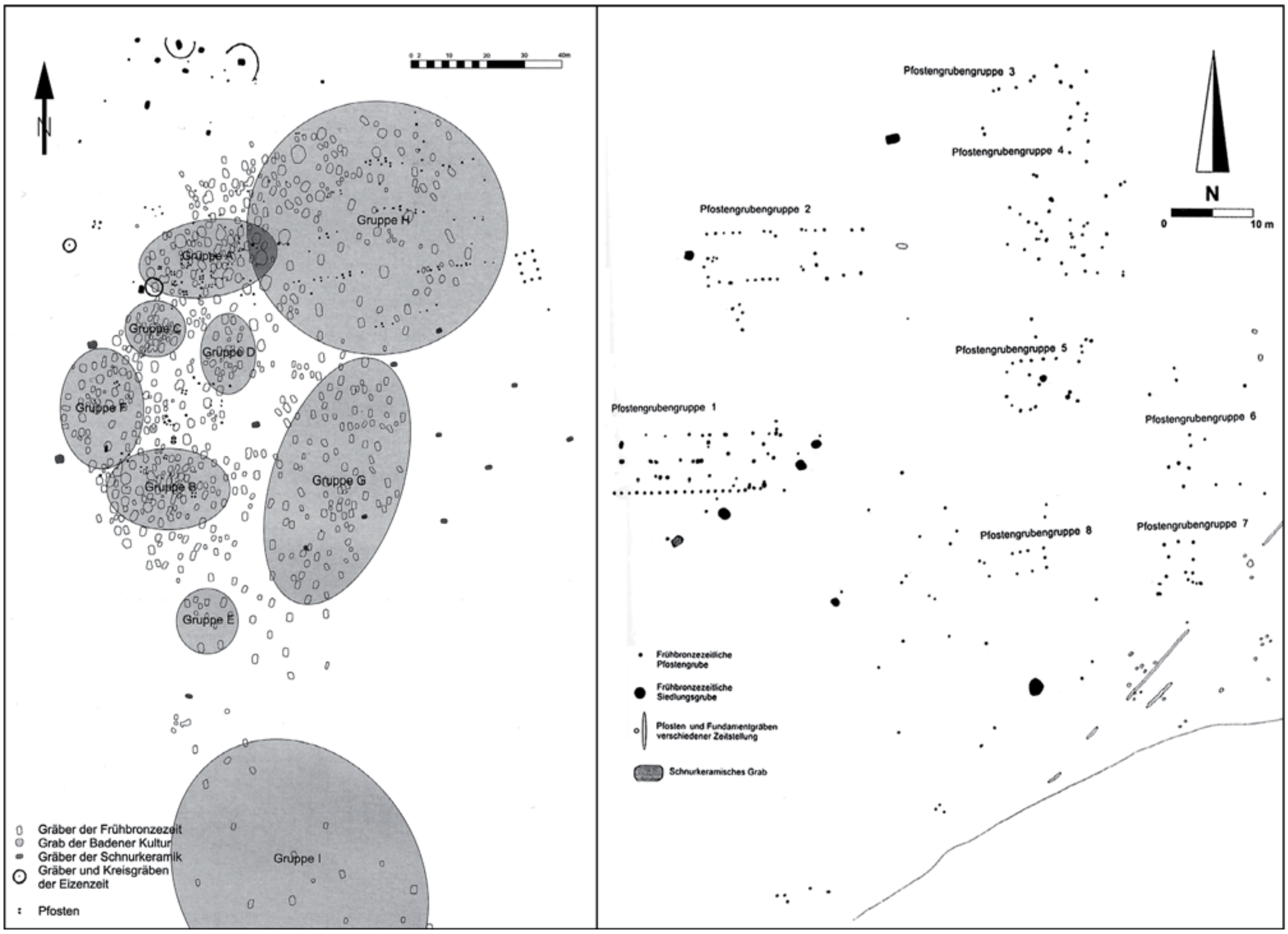


Fig. 8.9: Left: Cemetery of Franzhausen I, Austria – arrangement of the graves into nine groups thought to represent different communities or lineages (after Spatzier 2007, 221 fig. 2); right: Franzhausen – Early Bronze Age hamlet 1 (after Neugebauer/ Neugebauer 1997, 33 fig. 11).

units, such as members of different lineages for example, it cannot be taken for granted that all differences in material culture (grave goods) are due to chronological factors. It is possible instead that different kinds of ornaments, weapons or tools point to the coexistence of settlement units whose inhabitants did not share in all respects a common sense of local identity but traced back their origin to different ancestors or locations.

Obviously, such a model requires a closer look at Bronze Age cemeteries and settlements in future. Yet in general terms, it is likely that some kind of kinship-based system prevailed far into the Bronze Age (see also Kienlin 2007; in prep.). With regard to Singen we therefore have to take into consideration both of the following possibilities. If the members of the Singen community belonged to different lineages then they probably had access to different networks of exchange. There was not one line down which copper was traded to Singen, and variation in trace element content is not to be understood in purely chronological terms (i. e. mining activities proceeding along one particular ore vein with resulting changes in trace element content; Krause 1988, 242). Rather there was a whole range of different contacts and obligations towards the Alps. Copper artefacts were obtained by different avenues of exchanges as their trace element content hints at the exploitation of similar but distinct deposits by various local partners, who were operating mining activities on a small-scale seasonal basis comparable to the system suggested by O'Brien (2007, 24–27) for Mount Gabriel. Alternatively, at least in the Early Bronze Age A1, there were no such local communities at all, at least none based on mining and metallurgy, and members of lowland communities (in the widest sense) carried out mining activities on a seasonal basis themselves. It is possible that this involved the direct access of members from northern communities such as Singen into the mining districts. If there were communities closer by, copper was taken or exchanged north in various steps. But in any case the choice of ore deposits exploited and the path the copper subsequently took were governed by the kinship affiliations of those involved. Thus, copper with different trace element signatures found its way into the Singen grave groups at about the same time, and an approach like this might also account for the presence of just some Atlantic daggers alloyed with tin, while tin bronze otherwise is rare in Singen itself and its contemporaneous surroundings.

8.5 Kinship, Settlement and Seasonality in Alpine Copper Production

It is likely that in Singen times (c. 2200 to 2000 cal BC) there is no alpine settlement related to the mining and

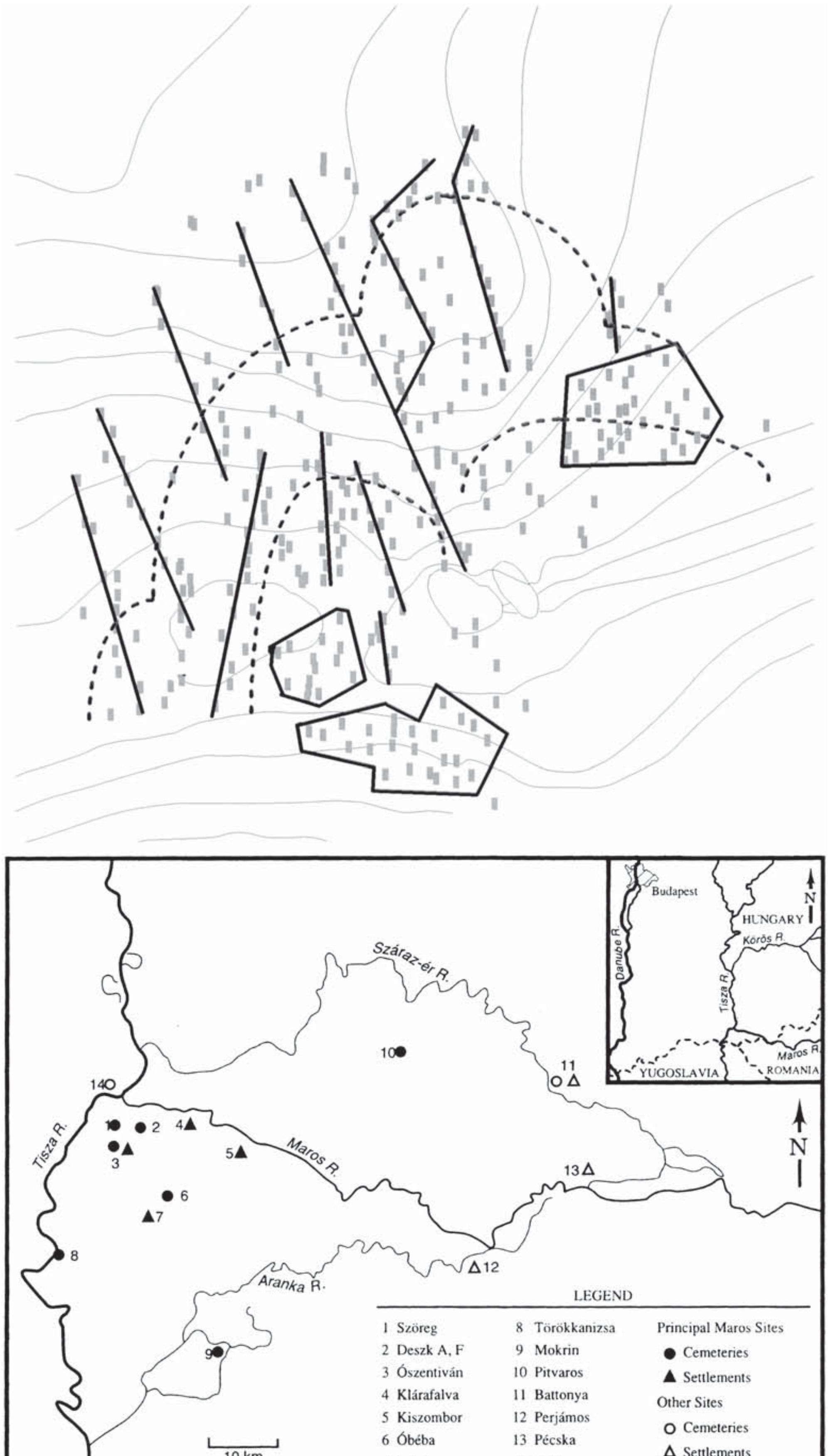


Fig. 8.10: Above: The Early Bronze Age cemetery of Mokrin, Serbia – arrangement of the graves into distinct rows and groups thought to represent different communities or lineages (after Wagner 2005, 116 fig. 4 and 126 fig. 13 – dashed lines: chronological phases after J. Wagner); below: Principal sites (settlements and cemeteries) of the Maros culture (after O'Shea 1996, 28 fig. 3.1).

production of Singen type copper at all, and we also lack evidence of mining itself. This finding is conspicuous with regard to the number of artefacts of Singen type copper known, yet it may also be symptomatic of the beginnings of copper production in the Alps. We are dealing with small-scale activities most likely organised on a seasonal basis, and we should not subsume this decentralised approach under a model of elite-driven mining and metallurgy. Instead there is evidence that Bronze Age settlement in the Alps was driven forward by communities with a subsistence-based economy initially drawing only limited advantage of alternative resources such as the alpine copper ore deposits. Only towards the second half of the Early Bronze Age is there evidence that in some areas this system evolved to comprise communities practising mining and metallurgy on a larger scale. But it wasn't until the Late Bronze Age that there is evidence of a marked increase in the organisational complexity of such activities.

Most authors would agree that there is little evidence of social ranking in cemeteries such as Singen (e. g. Strahm 2002, 186; Krause 2003, 259–261). However, the situation is not fundamentaly different during the subsequent Early Bronze Age as well (c. 2000 to 1800 cal BC and in fact beyond), when the existence of elites in the north alpine region is mainly deduced from the occasional occurrence of halberds and solid-hilted daggers (Krause 2002, 49–52; 2009, 53–56, fig. 8). In the area between the Rhine valley in the west and the Salzach valley in the east there is only a small number of solid-hilted daggers, and they hardly provide evidence of social differentiation in the Alps. Finds in graveyards such as Donat or in settlements such as the Buchberg near Wiesing can be designated as the big exceptions. Most daggers in general have been found as stray finds, often at high altitude and suggestive of an interpretation as ritual depositions. It is entirely unclear what proportion of the (male?) population was in command of a dagger and what social implications, if any, a metal hilt as opposed to an organic one carried. The evidence of elites remains elusive until the Late Bronze Age, when in the Inn and Salzach valleys large hoards and graveyards seem to indicate differences in economic prosperity and maybe differential access to status and power (Sperber 1999). We are entitled then to ask what kind of social structure may be deduced for the small-scale communities who settled on sites such as the small hilltops we generally find in the alpine valleys (fig. 8.11).

Even in the Únětice culture, the episode of 'princely' graves such as Helmsdorf and Leubingen may reflect the inherent instability of attempts to derive power from the control of material or symbolic resources rather than permanent social evolution (see chapter 5.3; Kienlin 2008c). In any case, with most of the halberds and daggers being stray finds and with no 'princely' graves or corresponding settlement evidence, it is controversial to propose that the north alpine region underwent a similar development. Against this background then it is argued that the occurrence of settlements such as Bartholomäberg reflects a general intensification in Early Bronze Age landuse in the Alps with the role of mining and the existence of elites in control of metallurgy in particular being overestimated. The attempt to draw a line from the mining for Singen copper to Bartholomäberg (e. g. Krause 1988, 238–240; 2005a, 391–401; 2007, 128; Krause/Oeggl/Pernicka 2004, 5–6) stems from the misguided notion that Bronze Age mining – and metallurgy in general – could only be carried out by hierarchically organised communities resident near the ore deposits. This approach falls short of representing a more complex development of organisational strategies involved in early mining. In particular, we have to take into consideration that in the beginning of the Bronze Age there were no alpine communities at all exploiting 'their' copper sources and trading copper to the lowlands. Rather Early Bronze Age metallurgy in the Alps may have begun with mining activities carried out by members of lowland communities on a seasonal basis (see also Pearce/De Guio 1999; Spindler 2003; Della Casa 2003; Pearce 2007). Such a pattern certainly is in line with the evidence of dagger finds as ritual depositions at high altitudes (see above) – the perfect ground for herders and shepherds that were assigned a special role in their societies and most likely involved in the first phases of copper exploration as well.

In a recent study Th. Stöllner showed that only the main valleys might have served as permanent settlement areas from the earlier phases of the Early Bronze Age onwards, and there were different regional trajectories and strategies involved (see Th. Stöllner in: Kienlin/Stöllner 2009, 83–88, figs. 15 and 16; Stöllner 2009). Typically, lowland sites formed the points of access to the alpine hinterland, and it was only in the younger part of the Early Bronze Age that the alpine side-valleys were colonised and occupied step by step. Earlier on, it is reasonable to argue for a seasonal mode of small-scale copper mining, but during the latter phase in particular the absence of mining traces even in the most promising 'copper districts' is conspicuous. Hence, it was suggested that once settled in the Alps, basic subsistence strategies were more important – at least initially – than the additional economic opportunities offered by mining and metallurgy. If there was copper exploitation on a seasonal and modest scale before, in some areas it apparently had to be abandoned due to the increasing efforts involved in agriculture and cattle breeding. It is thought unlikely, therefore, that copper exploitation played a role for territorialism and social diffentiation with hillforts and elites on top at least for the founding of the eastern Switzerland inner alpine settlements.

Although we still lack sufficient data on the settlement and subsistence basis there can be no doubt that small-scale communities gradually entered the inner alpine valleys during the first half of the 2nd millennium BC (see also Primas 2009, 196–200). In the Salzach and Saalach valleys this did not take place before the second half of Early Bronze Age (EBA A2, from the 18th century BC onwards), while first permanent settlements could have been established in the Tyrolean lowland shortly after 2000 BC. Some of these were drawing on copper deposits, but we lack comparable evidence from the alpine Rhine

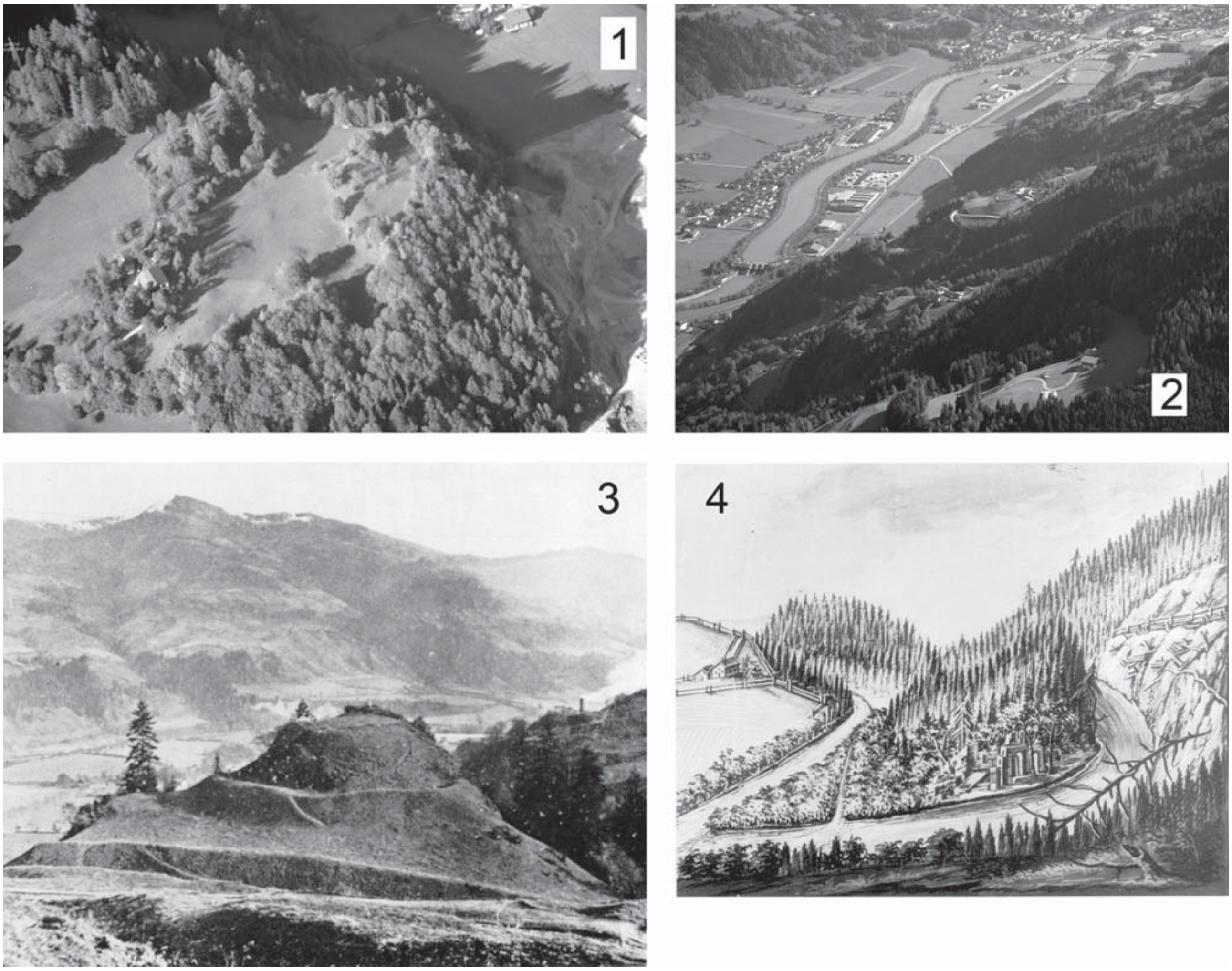


Fig. 8.11: Topography of Bronze Age settlements in the Salzach valley: 1 Klinglberg near St. Veit; 2 Höchbauer at the Einödberg, St. Johann; 3 Götschenberg near Bischofshofen, historical view about 1910; 4 Sinnhubschlößl at the confluence of Salzach and Fritzbach, historical view during 16th century AD (after Kienlin/Stöllner 2009, 89 fig. 17).

valley, indicating that such a specialisation was dependent on regionally specific factors. In another respect, however, the colonisation of the lower alpine Rhine valley between Bregenz, Vaduz and Sargans corresponds to the eastern Alps. There is little evidence that elites were involved in Early Bronze Age settlement, and it should be considered that small-scale communities entered the alpine valleys in the footprints of those who first explored those areas in their search for pastoral land and mineral resources. This is a pattern similar to that suggested for other regions and prehistoric periods as well. A seasonal mode of exploitation is known from ethnography and is characteristic for wide-ranging extensive land-use strategies. Such expeditions are often headed by experienced people who know the hunting grounds, trackways, arable pastoral grounds and resting sites as well as the mineral deposits; an approach to early mining which typically involves a flexible use of various raw material deposits but obviously does not rule out that abundant sources were repeatedly visited.

Drawing all evidence together, the following pattern of Early Bronze Age landuse and settlement in the Alps may be suggested. After a first phase of expeditions carried out in connection with pastoral activities, small communities chose arable grounds situated on medium altitude terraces to establish permanent settlements on the basis of agricultural activities. The choice of hilltops for the settlement itself might indicate rivalry with neighbouring groups, but we should not underestimate the need of cooperation in a new environment such as the Alps. In some cases these groups apparently continued exploiting copper ore deposits by seasonal or sporadic visits but, initially, mining may even have decreased as a consequence of permanent settlement and agriculture in some areas. In others we witness, in the long run, some concentration on more abundant and sustainable ore deposits. Although quite obviously not all of these communities were in an economic position for such an intensification of mining and metallurgy. This may be the reason why only some of these communities could establish intensive copper production as we know it from the 16th to 14th centuries BC (Middle Bronze Age) in the Mitterberg area (e. g. Eibner 1993; Stöllner/Eibner/Cierny 2004; Bartelheim 2007). Singen type copper seems a perfect example for an initial Early Bronze Age exploitation and

distribution pattern that was based on established economies in the alpine foreland. Both the archaeological record and ethnographic evidence strongly suggest that there is no need for a hierarchically organised society for such an approach to mining. Alpine metallurgy did not evolve in this direction until very much later.

9
Some Concluding Thoughts

Some of the findings discussed in the preceding chapters of this volume require further work. The formation of the different types of oxide inclusions in Eneolithic/Copper Age axes, for example, clearly calls for an experimental approach to be more precise on the differences in casting methods postulated. The patterning observed, however, both in the development of methods of casting and forging clearly points to the potential of metallography to provide an important contribution to our knowledge of early metallurgy. Certainly, this is not a method to draw equal in numbers with the thousands of compositional analyses that were done over the last decades. But it is important to move the application of metallography beyond the mere characterisation of individual objects published in some out-of-the-way journals to comprise larger series of artefacts to enable us to recognise patterning and change in basic production parameters. An attempt was made in this study to show that new kinds of information thus become available, new questions concerning cognitive aspects of early metalworking can be asked and, at least for some of them, an answer may become feasible.

However, beyond mere technology it was a central aim of this study to contribute to our understanding of early metallurgy in a wider social and cultural context. It is up to the reader to decide if the approach taken via the critique of evolutionist notions in both our conceptions of metalworking and society is convincing, and some of the ideas put forward will certainly provoke contradiction. Nor is the question of 'metal and society' a new one. On the contrary, this kind of 'social archaeology' style approach has more recently gone out of fashion. Some avoid tackling this problem on a local scale by a return to the broad picture of the emergence and spread of metallurgy in the Old World. Others in a post-processual tradition focus, for example, on metaphorical concepts and the perception of mines in the landscape. Similarly, both the potential of metal objects for practical use and the question of their potential to confer status or prestige seem old-fashioned vis-à-vis the current interest in ritual aspects of hoarding and the demarcation of ritual landscapes by the deposition of valued copper and bronze objects.

Yet there is an enduring interest in craft specialisation and the impact of metalworking on society, and the more overtly 'theoretical' archaeology moves into other directions, the more common sense argument and what have been called 'meta-narratives' above gain ground again. It is unfortunate that both in specialist studies and recent handbooks "metals make the world go round", when precisely this view of causality was hotly debated some decades ago. Possibly, the dissatisfaction felt with this development is also related to the specific continental, i. e. German, background and training of the author. But it is certainly a mistake that discussions in 'theoretical archaeology' should move on to the next fashionable approach and leave central areas of interest uncovered. Notions of 'progress' and 'evolution' towards increasingly better types of copper or copper-based alloys and better technical solutions in their production and working show a related development. In this case it is specialist studies drawing on scientific or experimental data that may imply a more differentiated picture. But many working in this field either refrain from the interpretation of their data in terms of wider relevance or being scientifically trained adhere to a broadly evolutionist approach themselves. Thus the expectations of a wider archaeological audience tend to be confirmed rather than entering a true discourse.

None of the metallographic findings discussed above is supposed to radically change our notions of early metalworking; and for sure some of the ideas put forward on the meaning of its products and its social context will be controversial. But if this study is accepted as an attempt to bring the scientific study of early metallurgy one step closer to wider intellectual debates in archaeology and if it stimulates discussion the time spent writing it is thought worthwhile.

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Appendix I:
Methods Applied and Outline of the Interpretation of Eneolithic/Copper Age and Bronze Age Microstructures*

* For a more comprehensive review of the methods applied in the metallographic examination, the interpretation of the microstructural evidence and the dependency of the microstructures of copper and copper alloys on production parameters during casting and forging the reader is referred to: Northover 1989; 1996; Scott 1991; Schumann 1991; Wang/Ottaway 2004; Kienlin 2008a (appendix I and II).

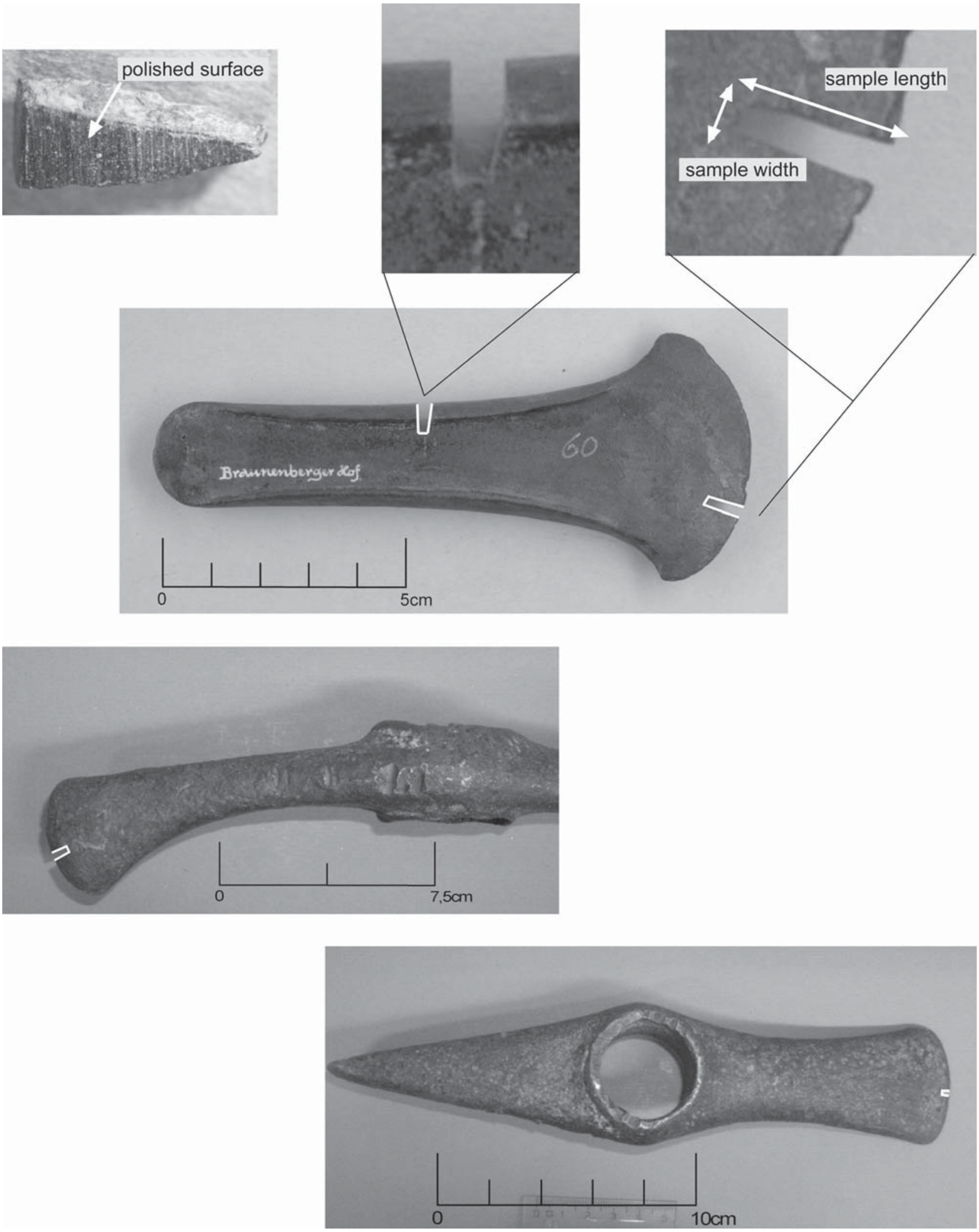


Fig. AI-1: Sampling procedure. Systematic sampling took place on the blade area which is most promising in terms of providing information on the methods of production and the manipulation of mechanical properties by smithing (plus an occasional sample from the flanges of some Early Bronze Age axes). Sampling was carried out on a well-preserved area of the blade using a fine jeweller's saw. The samples removed were approximately 0.5 cm deep and 0.1 cm thick.

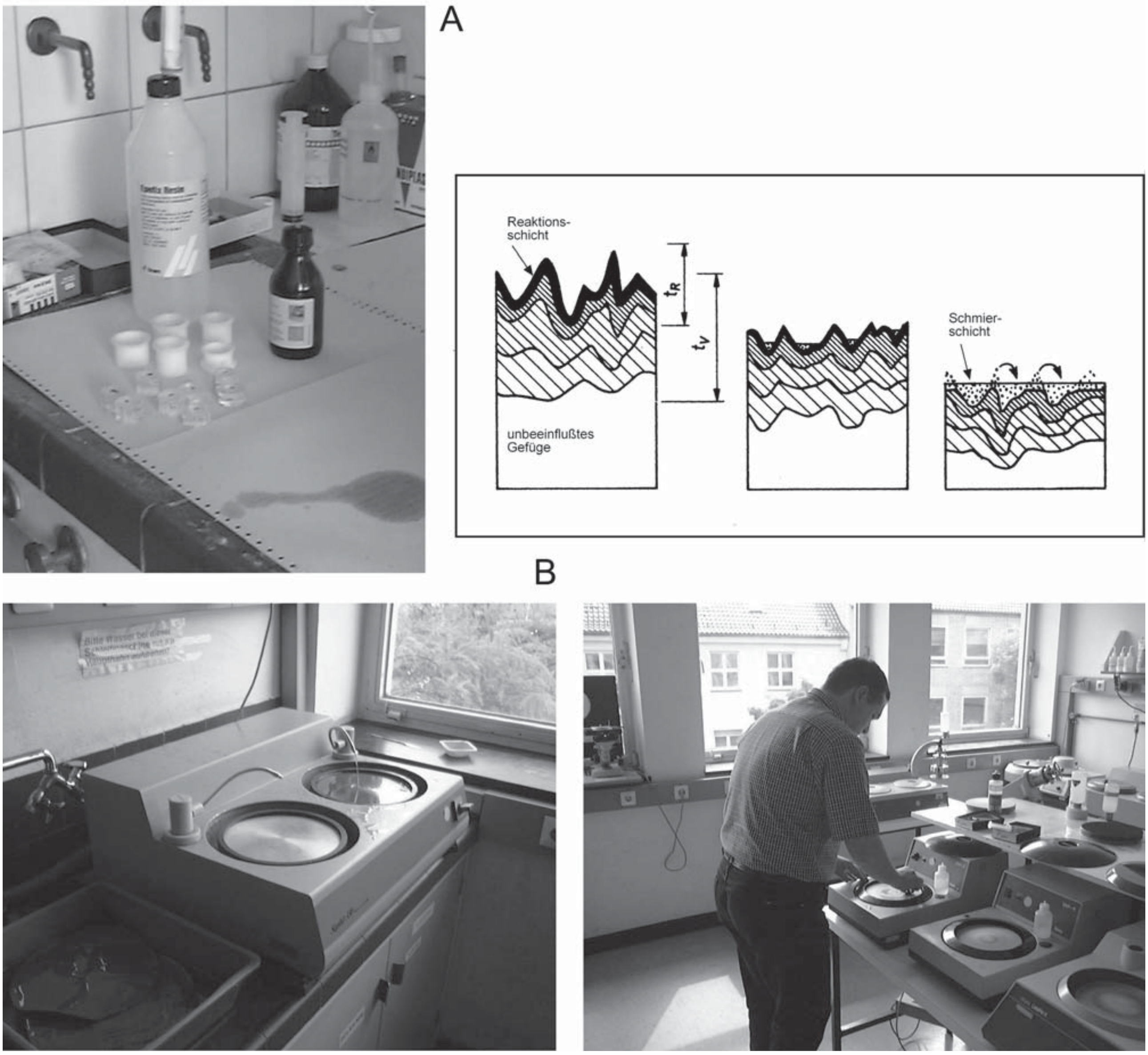


Fig. AI-2: Sample preparation. A: mounting; in order to avoid changes in the microstructure a cold mounting resin was used. In view of some rather porous samples a mounting under vacuum proved to be advantageous. B: grinding and polishing; due to the limited thickness of the samples the grinding was conducted on fine-grained silicon carbide abrasive paper. The polishing was done in three steps with diamond paste with grain sizes of 6 µm, 3 µm and 1 µm on cotton towels; the draft illustrates the development of the sample surface upon polishing.

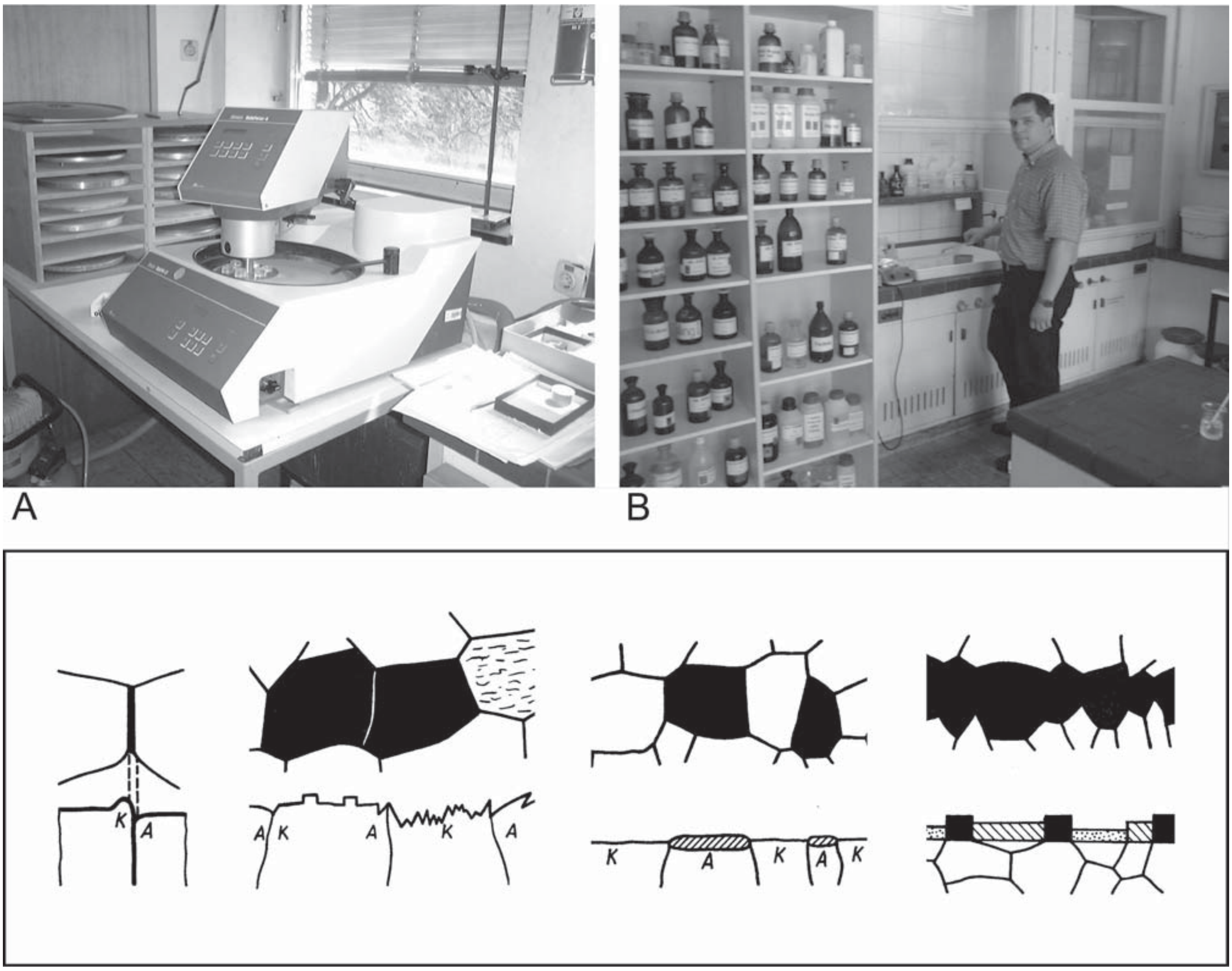


Fig. AI-3: Sample preparation. A: polishing; good results were achieved with a final oxide polishing (Al_2O_3 suspension) with a long polishing time (1.5 hours) and very limited pressure on Struers RotoPol-31. B: etching; in most cases an etching with an alcoholic ferric chloride solution (100 ml ethanol [96 % concentration], 20 ml HCl [32 % concentration], 5 g iron[III]-chloride) provided good results. In addition, colour etchings were used. The draft illustrates the different mechanisms involved in the etchings used – grain boundary attack, selective removal of material or the formation of a surface layer on particular grains.

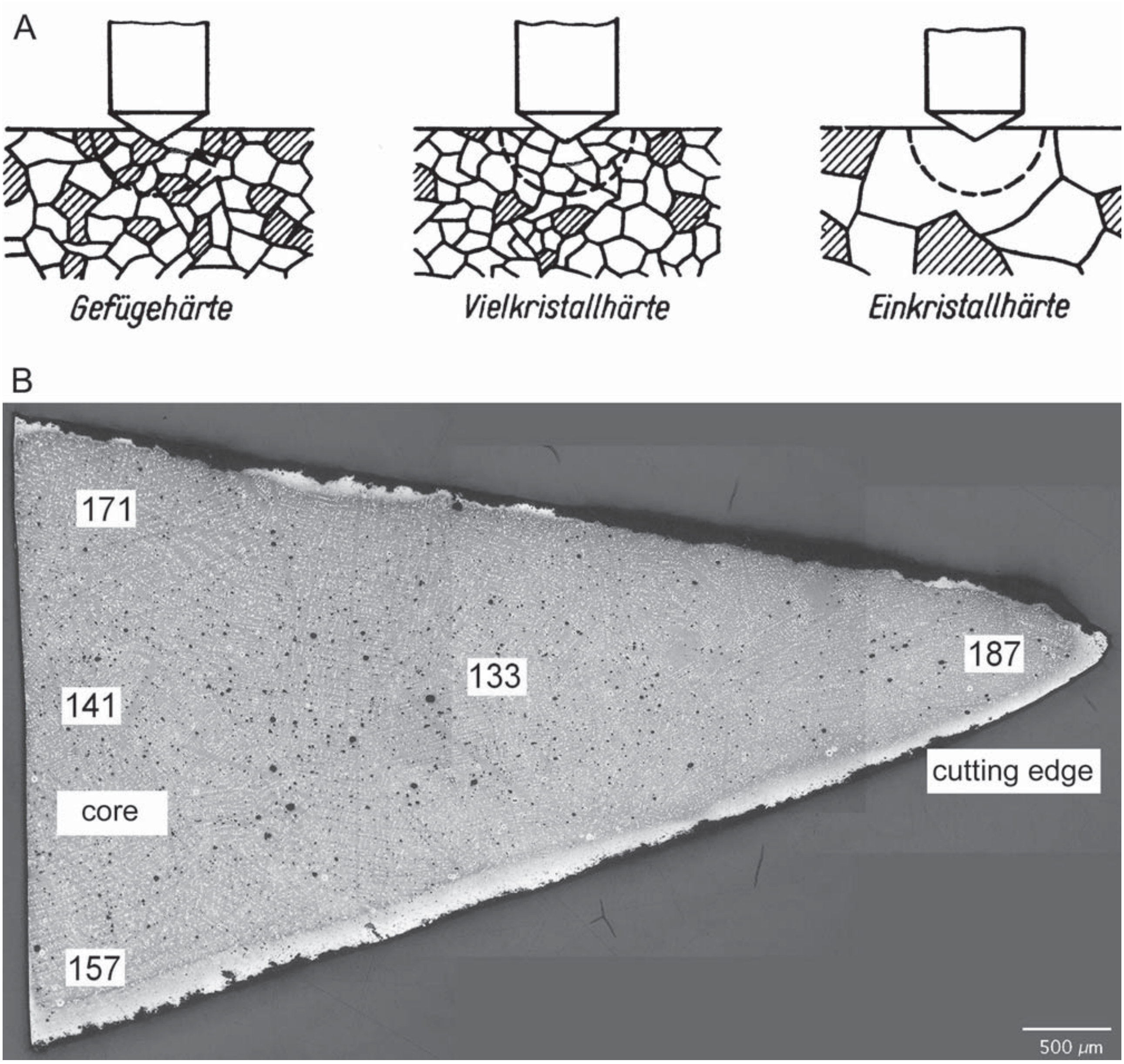


Fig. AI-4: Hardness testing. Due to the limited thickness of the samples the hardness was determined using a Vickers microhardness test (HV0.1) which at the same time allowed a targeted selection of the sample area. A: The draft indicates the influence of various microstructural components on the hardness readings obtained. B: On each sample five measurements were taken, starting at the tip (cutting edge) and working back to the core and outer backward surface. Typically, the cutting edge and surface are more heavily affected by cold work and harder than the core area (see also fig. AI-5).

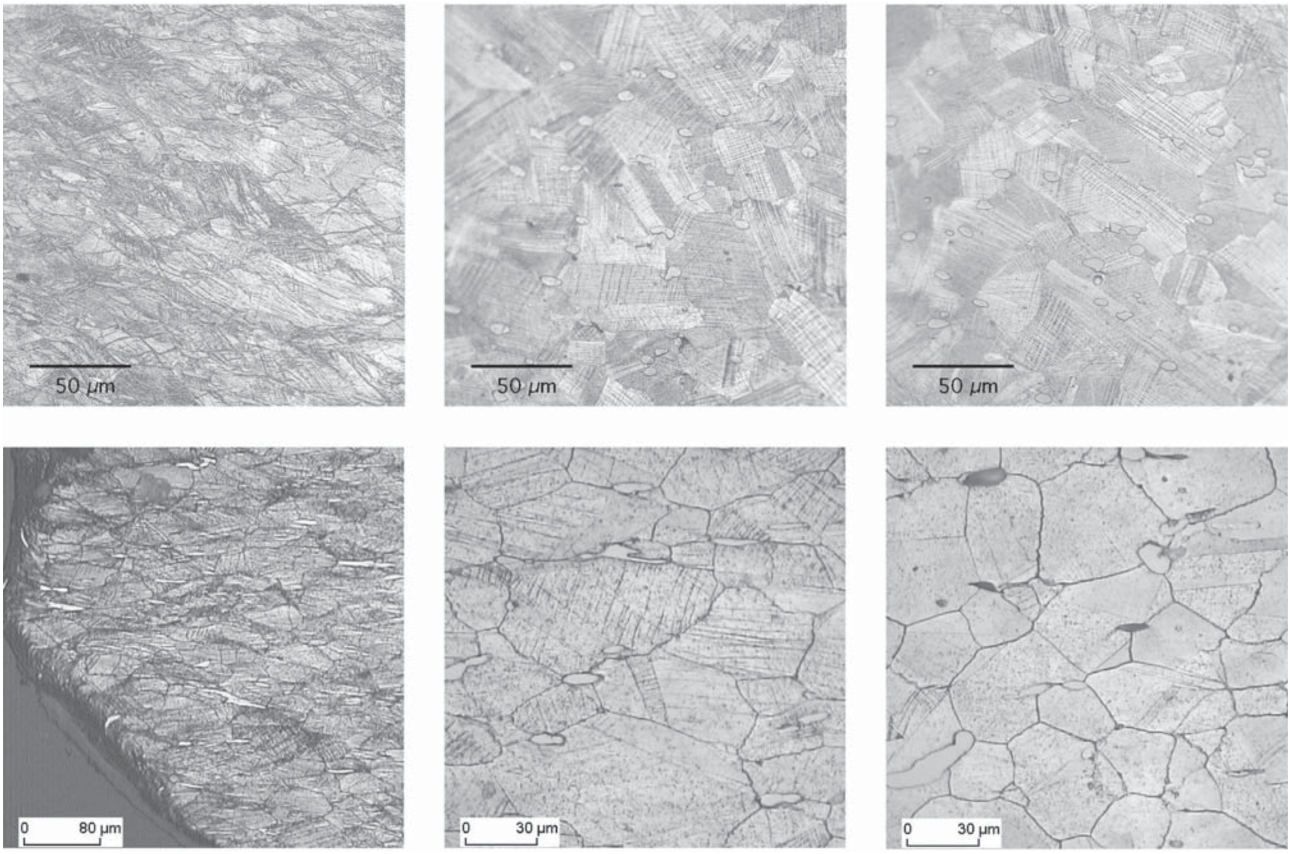


Fig. AI-5: The effect of differential cold work (and consequently: work hardening, see also fig. AI-4) from the cutting edge (left) to the core (right) of two samples. Deformed grains and densely packed strain lines in various systems close to the cutting edge; undeformed grains with (top right) and without (below right) strain lines in the core area illustrate the decreasing impact of cold work on the core area. Top row sample: heavily deformed sulphide inclusions close to the cutting edge (left) and hardly deformed sulphide inclusions in the core area (right), indicative of a decreasing total reduction in thickness as one moves backwards on the sample (see fig. AI-4).

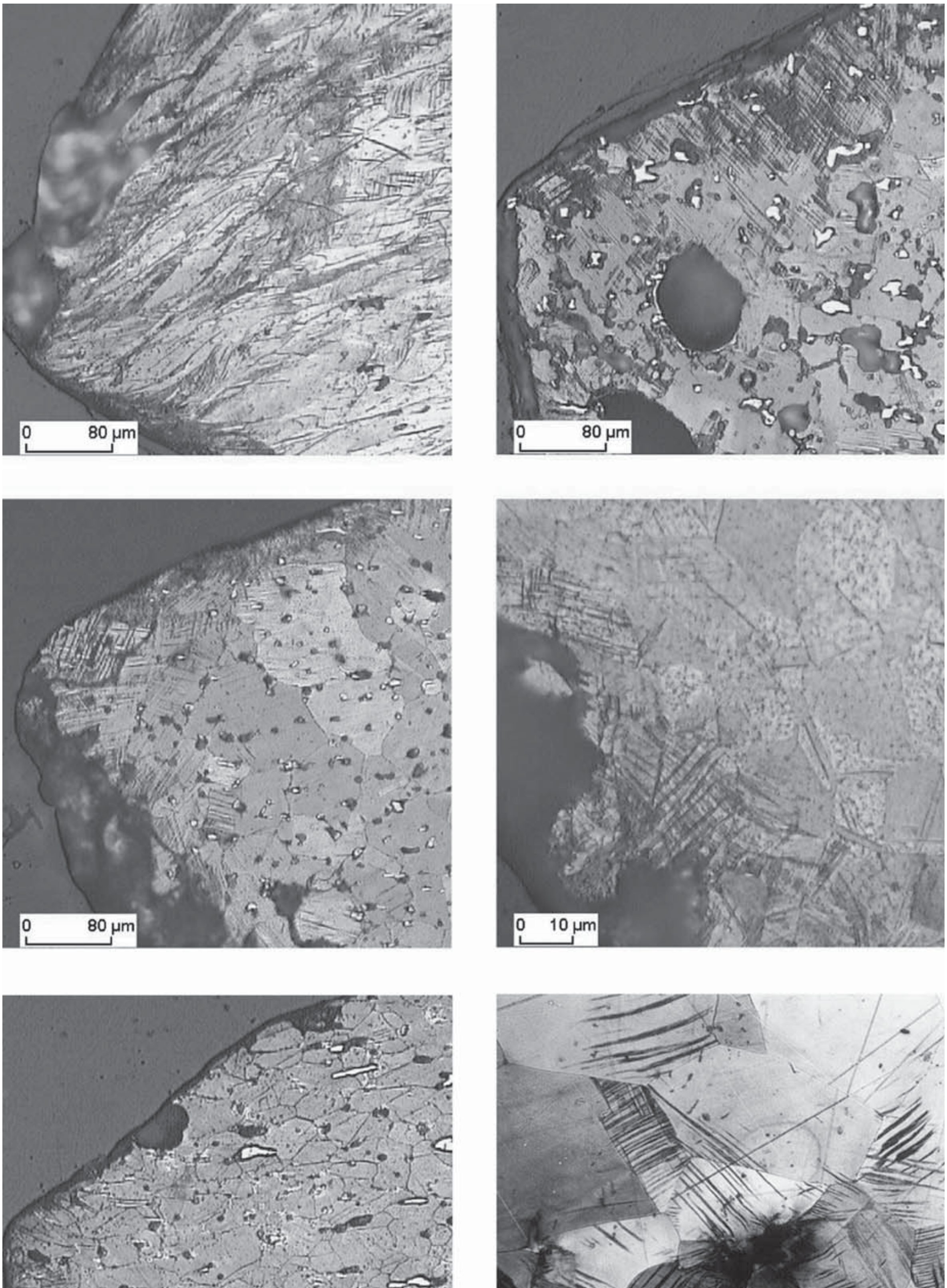
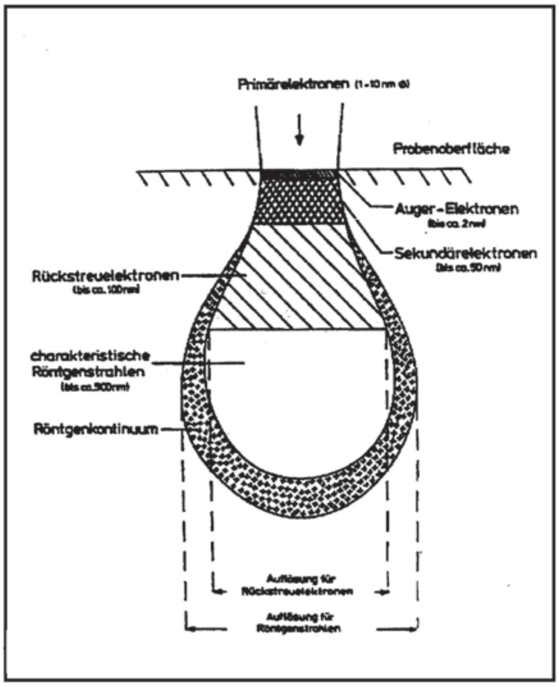


Fig. AI-6: Use wear close to the cutting edge of a number of samples (below right: after Northover 1996, 328 NMK 332, fig. 332.1). Note the local occurrence of this feature close to the tip of the sample only compared to the more substantial effect of cold work (see also fig. AI-5).



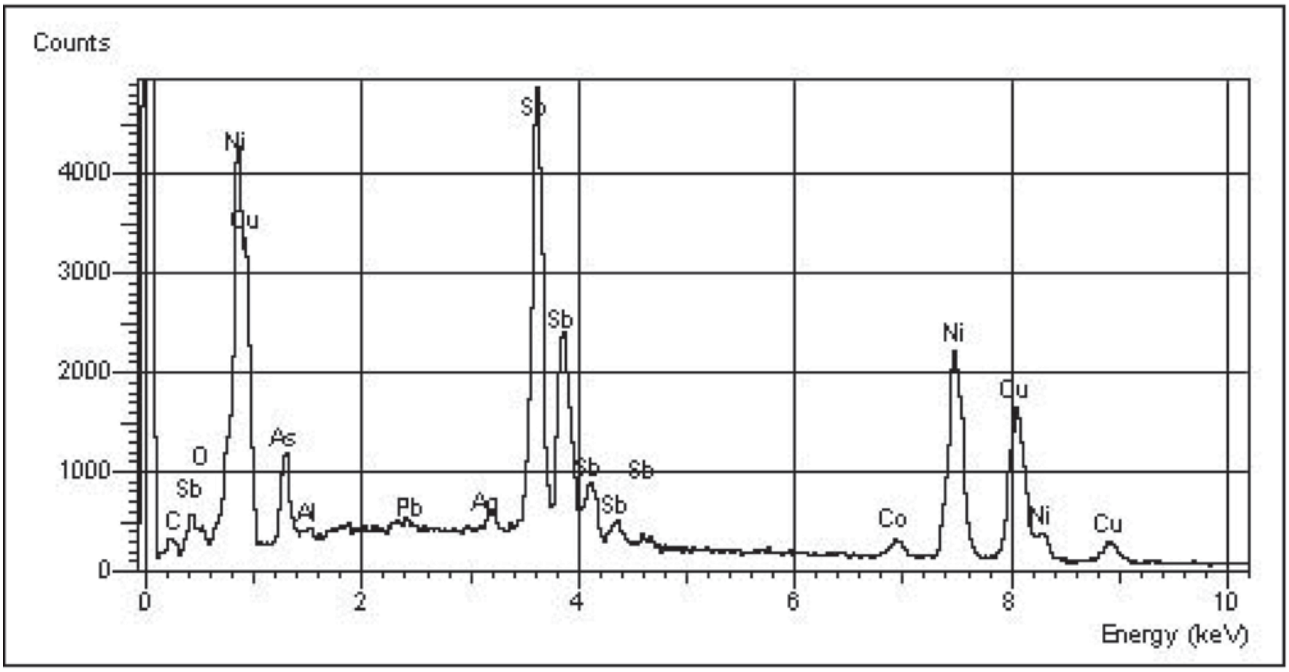


Fig. AI-7: Compositional analysis. The composition of the samples was determined in the scanning electron microscope (SEM) by means of energy dispersive X-ray spectroscopy (EDX). On the polished surface of the samples bulk and point analyses were carried out to determine the overall composition and the composition of individual microstructure components (all information given in weight-%).

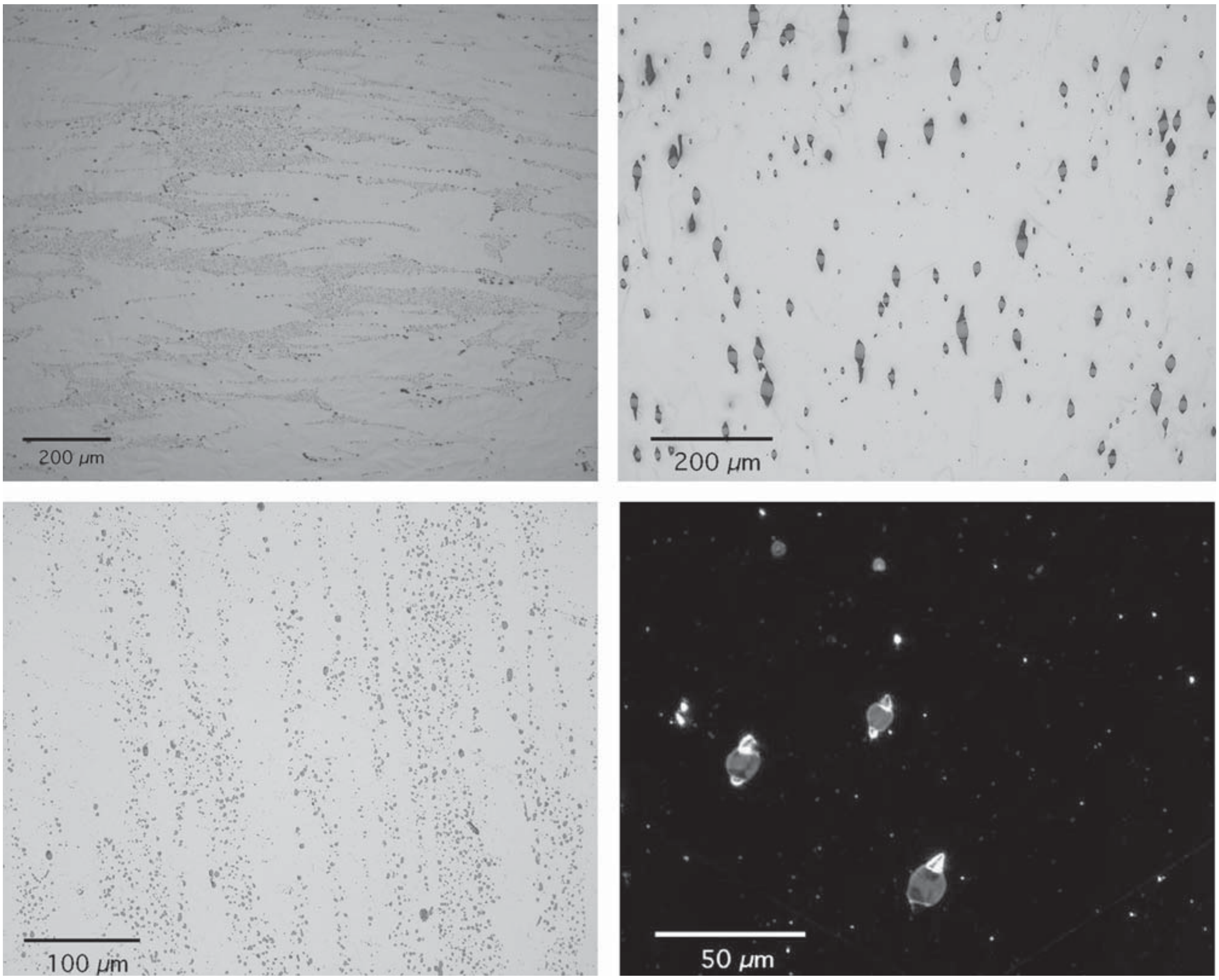
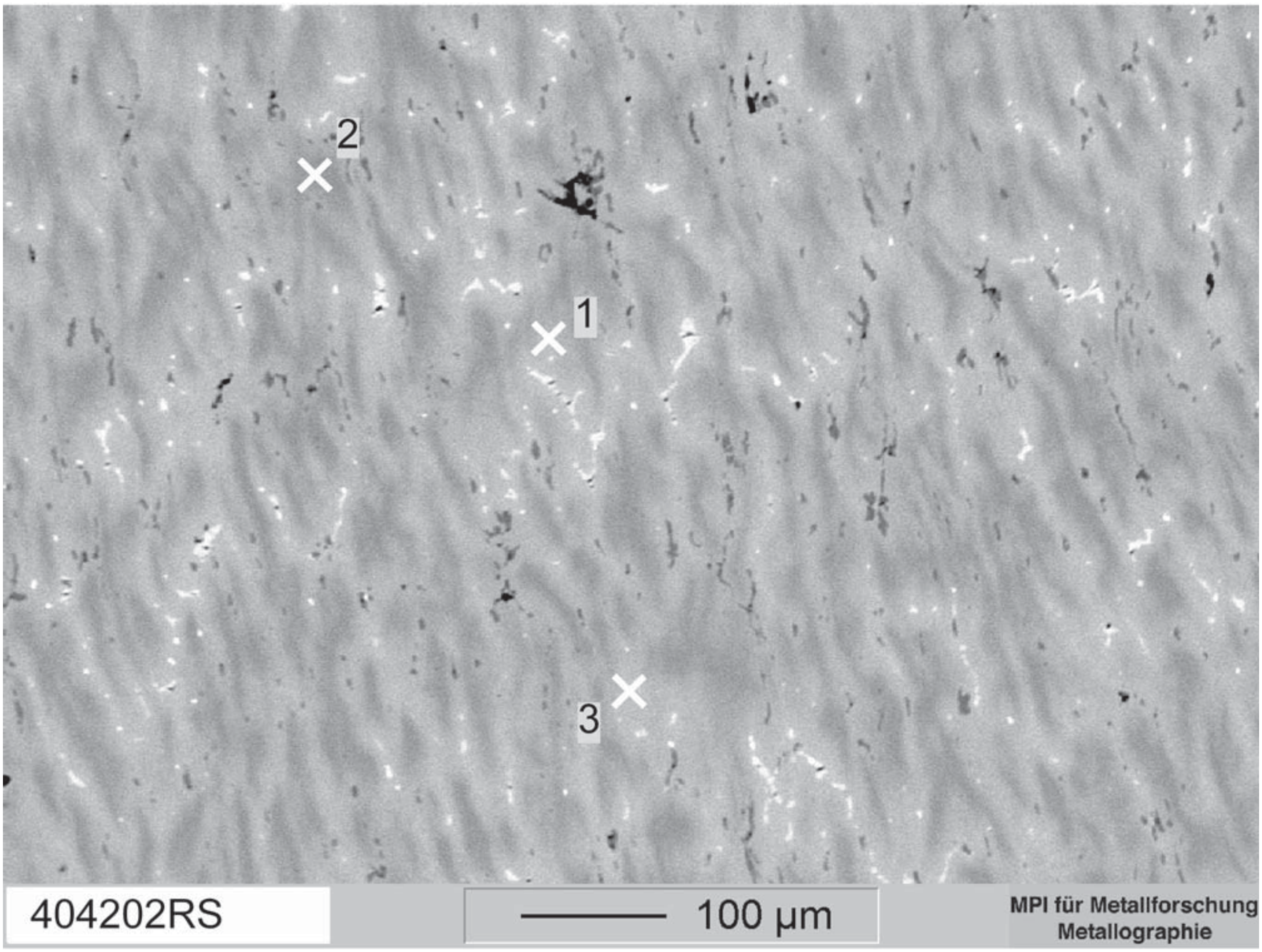


Fig. AI-8: Oxide inclusions (phases) in Eneolithic/Copper Age axes. Left: the ($Cu+Cu_2O$)-eutectic in older Eneolithic/Copper Age horizon 1 axes. Right: copper oxide particles and mixed copper-arsenic oxide particles in younger Eneolithic/Copper Age horizon 2 axes.



sample no. 404202	*Cu*	*S*	*Sn*	*Pb*	*As*	*Sb*	*Ag*	*Ni*	*Co*	*Fe*
EDX, matrix [point 1]	92.47	0	6.2	0	0.65	0	0.15	0.53	0	0
EDX, matrix dark [2]	94.93	0	3.79	0	0.37	0.36	0.15	0.4	0	0
EDX, matrix light [3]	88.04	0	10.1	0	0.52	0.49	0.3	0.59	0	0
EDX, matrix, mean	91.81	0	6.68	0	0.51	0.28	0.2	0.51	0	0
EDX, larger sample area	88.36	0	9.61	0	0.54	0.64	0	0.84	0	0
EDX, dark grey phase	76.05	21.36	0	2,32	0	0	0.26	0	0	-
EDX, whitish phase	61.88	0	32.9	0	0.39	1.89	0.53	2.41	0	-
EDX, whitish phase	61.48	0	32.9	0	0.71	2.43	0.37	2.03	0.13	-
SAM II,3 2765	-	-	>10	0,12	0.72	0.41	0.08	0.36	0	0

Fig. AI-9: Coring and phases in Early Bronze Age tin bronzes. Lighter areas of the copper matrix rich in tin [3] and darker areas depleted of tin [2]; whitish phase:α/δ-eutectoid (see also fig. AI-10); dark grey phase: copper sulphide.

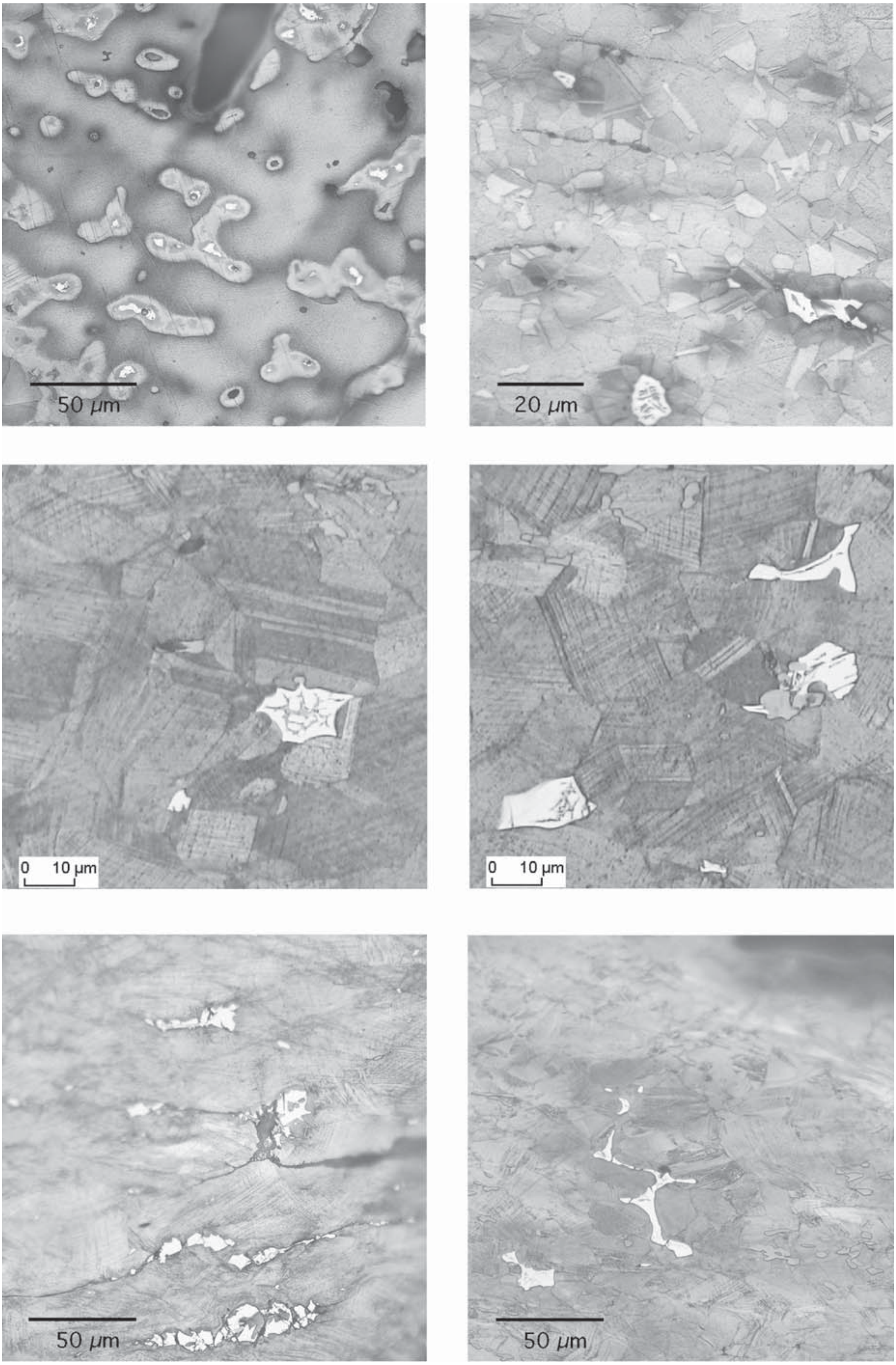


Fig. AI-10: Phases in Early Bronze Age tin bronzes. The α/δ-eutectoid; after casting this phase is located in between the copper-rich dendrites (top left), and it is broken up as a result of subsequent mechanical deformation (cold work; below left).

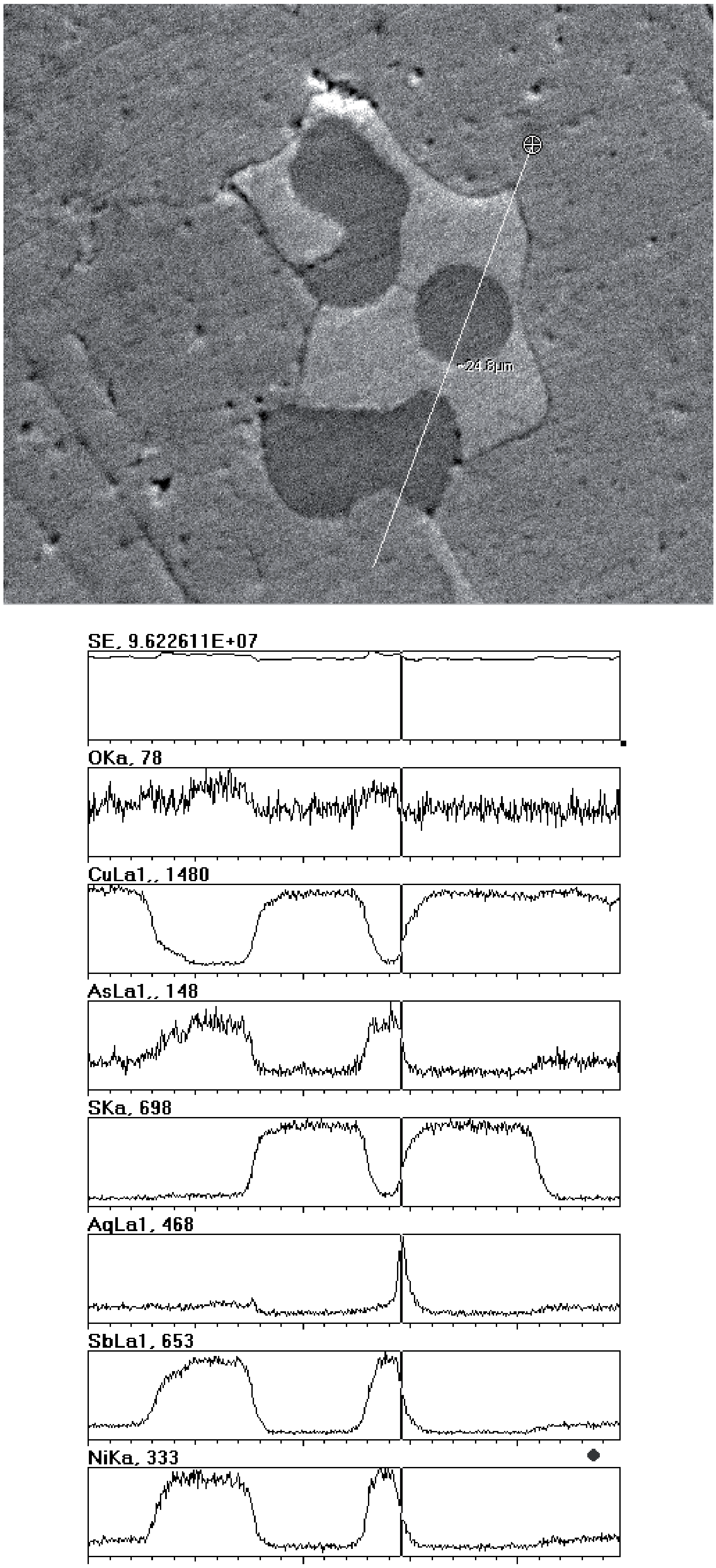


Fig. AI-11: Phases in Early Bronze Age fahlore copper (linescan). Intermetallic phases (light grey) rich in arsenic, antimony, silver and nickel; copper sulphide (dark grey).

% cold work	*copper matrix (last step of cold work)*	*inclusions and phases (total reduction in thickness)*
10–20 %	slip traces / strain lines	
>20 %	duplex slip / several systems of strain lines	
>25 %		oval
>30 %	deformation of grains	
>45 %	grains elongated / heavy deformation of grains	
>50 %		heavily deformed / elongated / broken up
>70 %	'blocky' structure	
>80 %	structure destroyed / no grains discernible anymore	stringers

Fig. AI-12: The effect of cold work on the microstructure of copper and copper alloys (after Northover 1989, 112–113, fig. 13.2; Kienlin 2008a, 49 tab. 2).

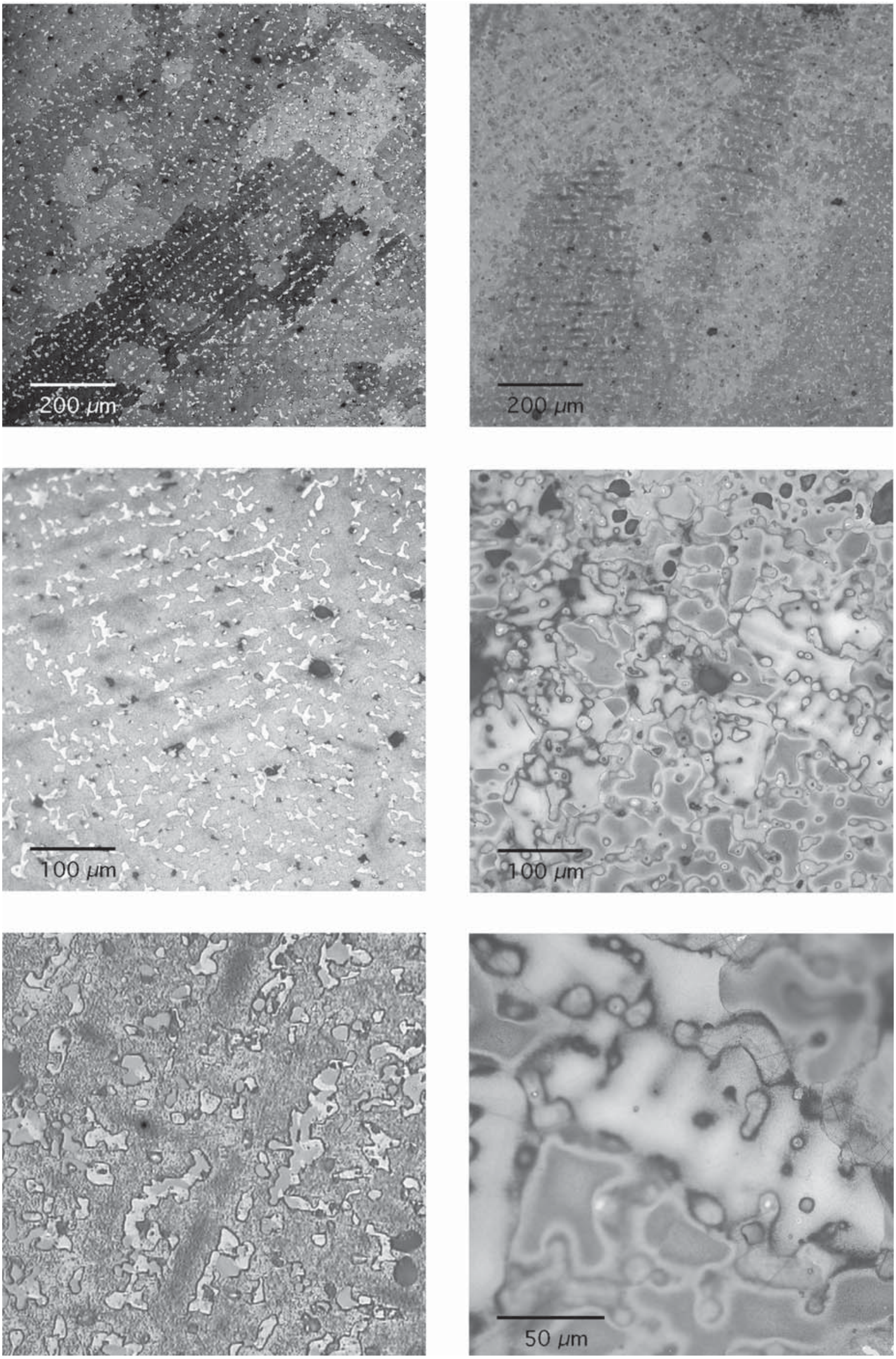


Fig. AI-13: As-cast microstructures. Large irregularly formed casting grains (top row), coring in the copper matrix and interdendritic patterning of additional phases (middle and below).

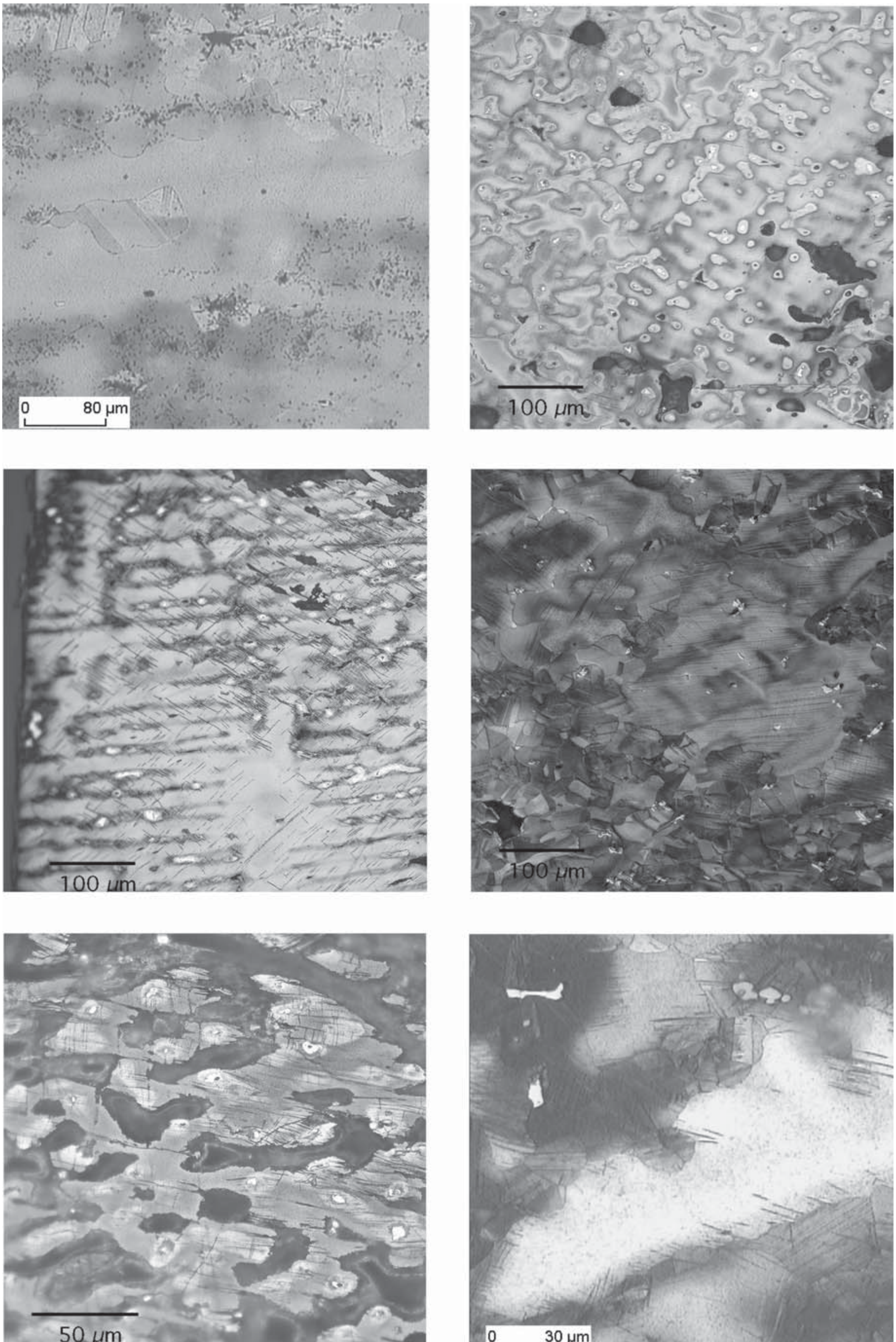


Fig. AI-14: Partly recrystallised (top left, middle right) and slightly deformed as-cast microstructures with occasional strain lines.

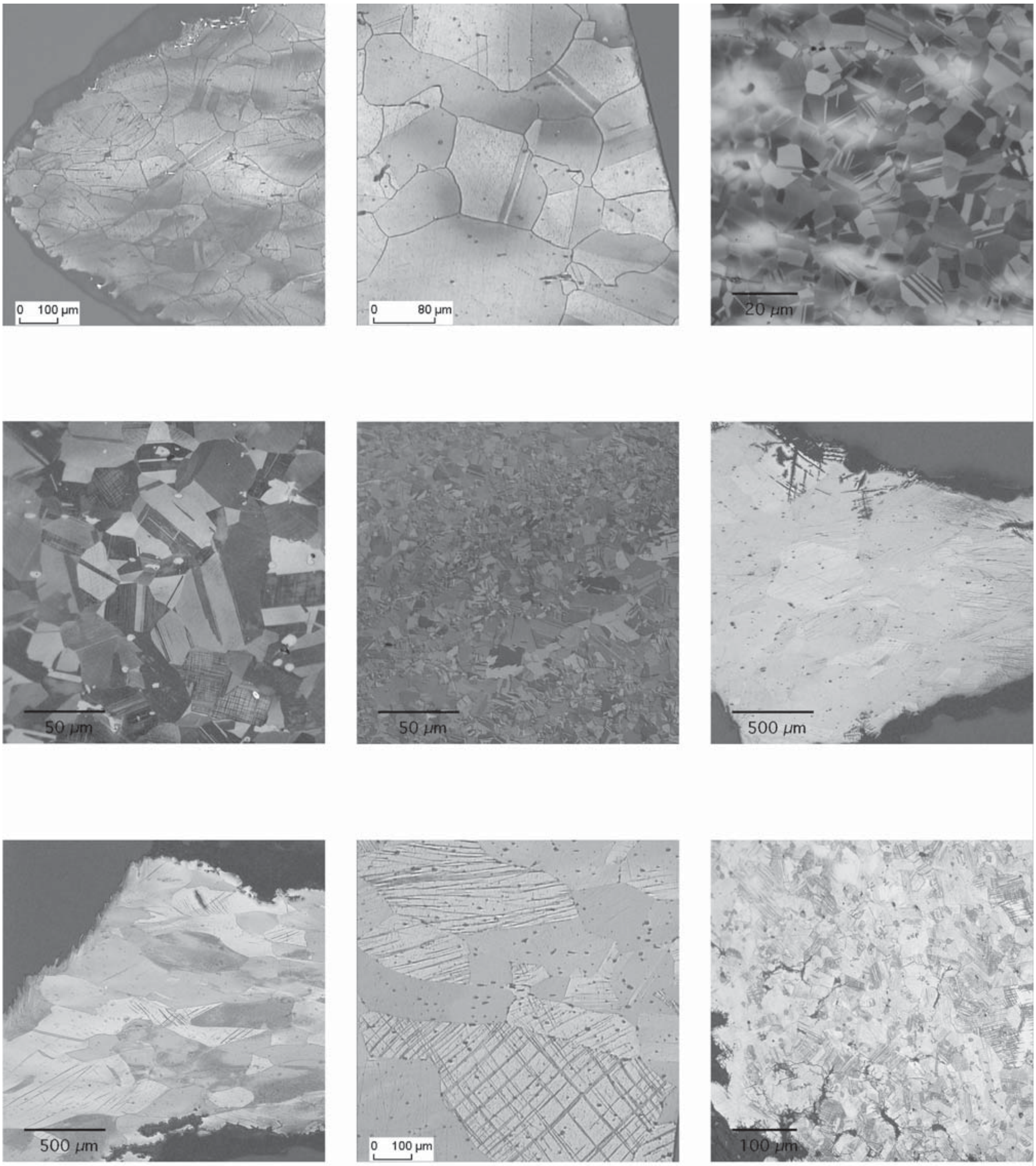


Fig. AI-15: Fully recrystallised microstructures with annealing twins and occasional strain lines indicative of the early stages of a second cycle of cold work. Note the differences in grain size as a result of the unequal strength of previous cold work and composition of these samples (phases etc.).

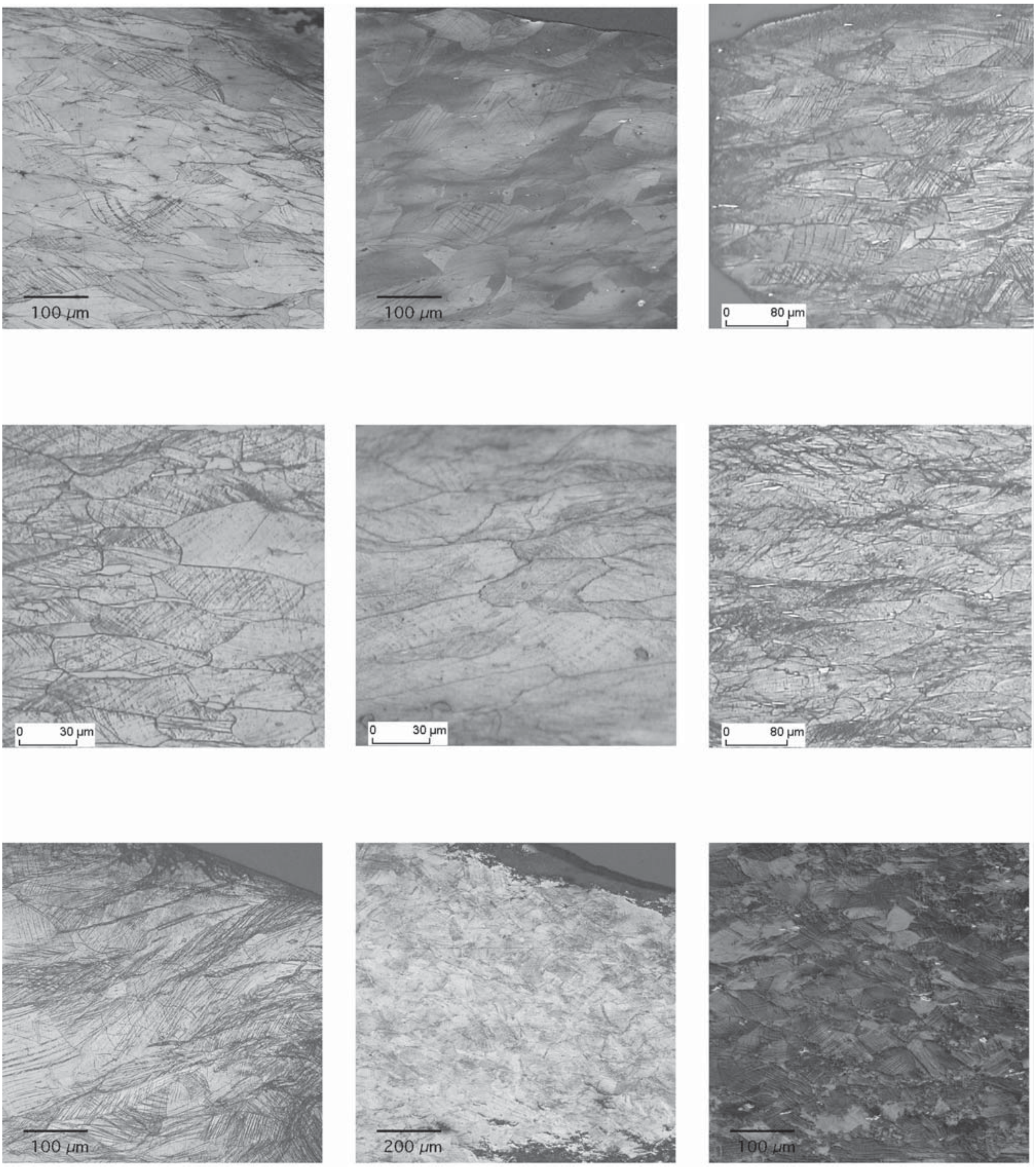


Fig. AI-16: Strength of final cold work. Fully recrystallised microstructures with moderately deformed grains, deformed annealing twins and strain lines indicative of a reduction in thickness during final cold work in the 35 % to 40 % range.

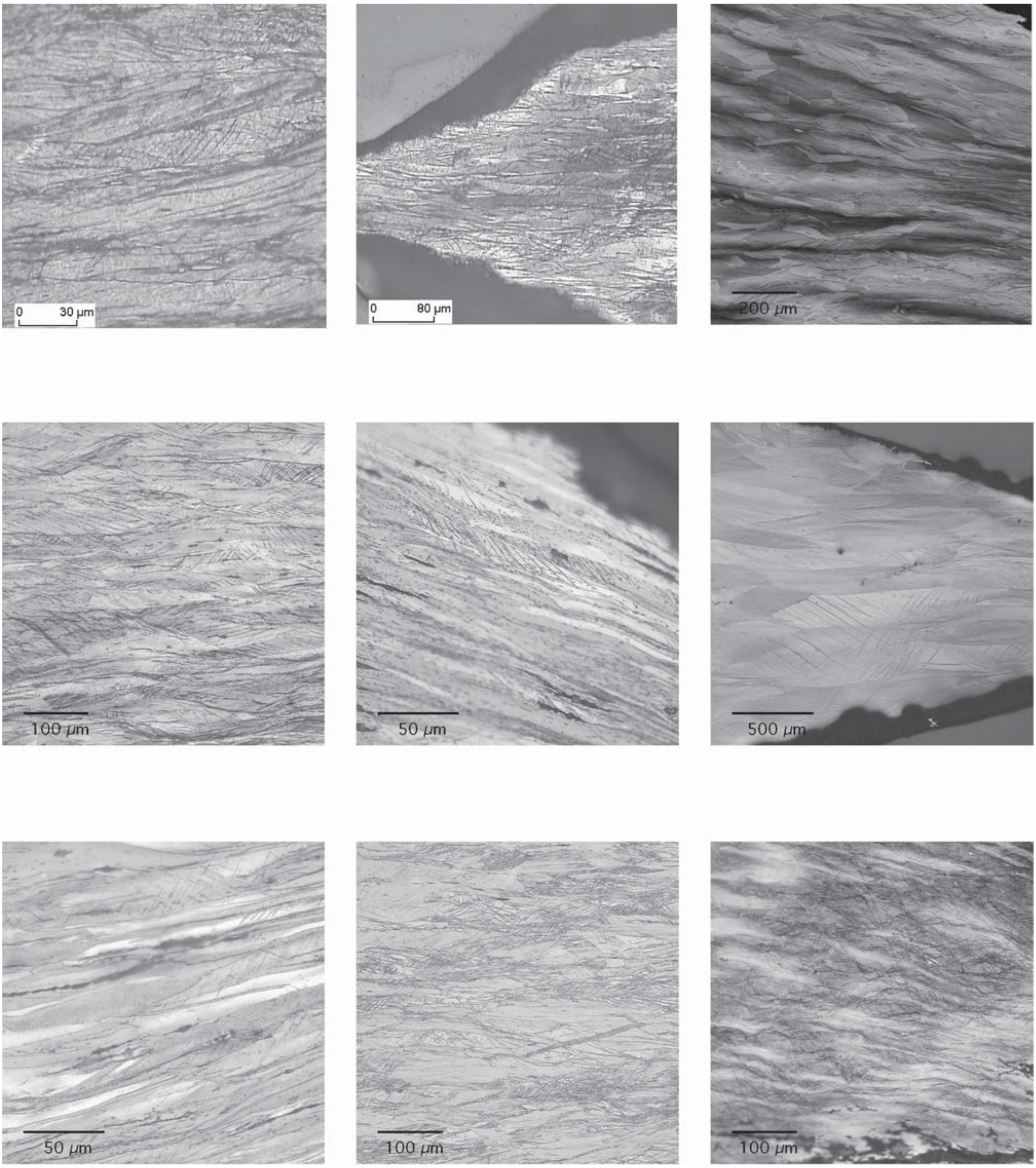


Fig. AI-17: Strength of final cold work. Fully recrystallised microstructures with heavily deformed grains (45 % to 50 % reduction in thickness).

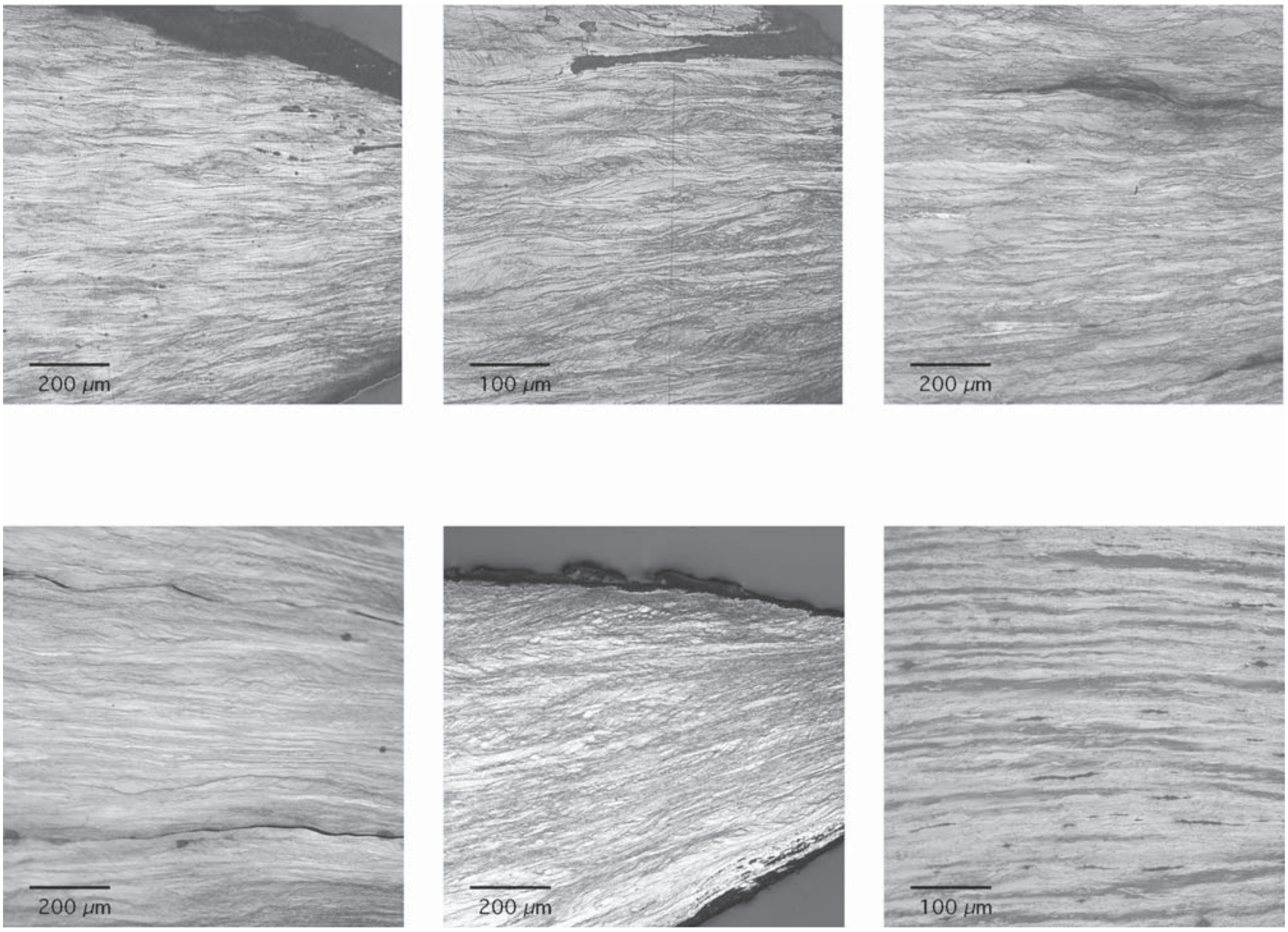


Fig. AI-18: Strength of final cold work. Fully recrystallised microstructures with an extreme elongation of grains, porosity and phases due to heavy cold work in the final step in excess of 50 % reduction in thickness.

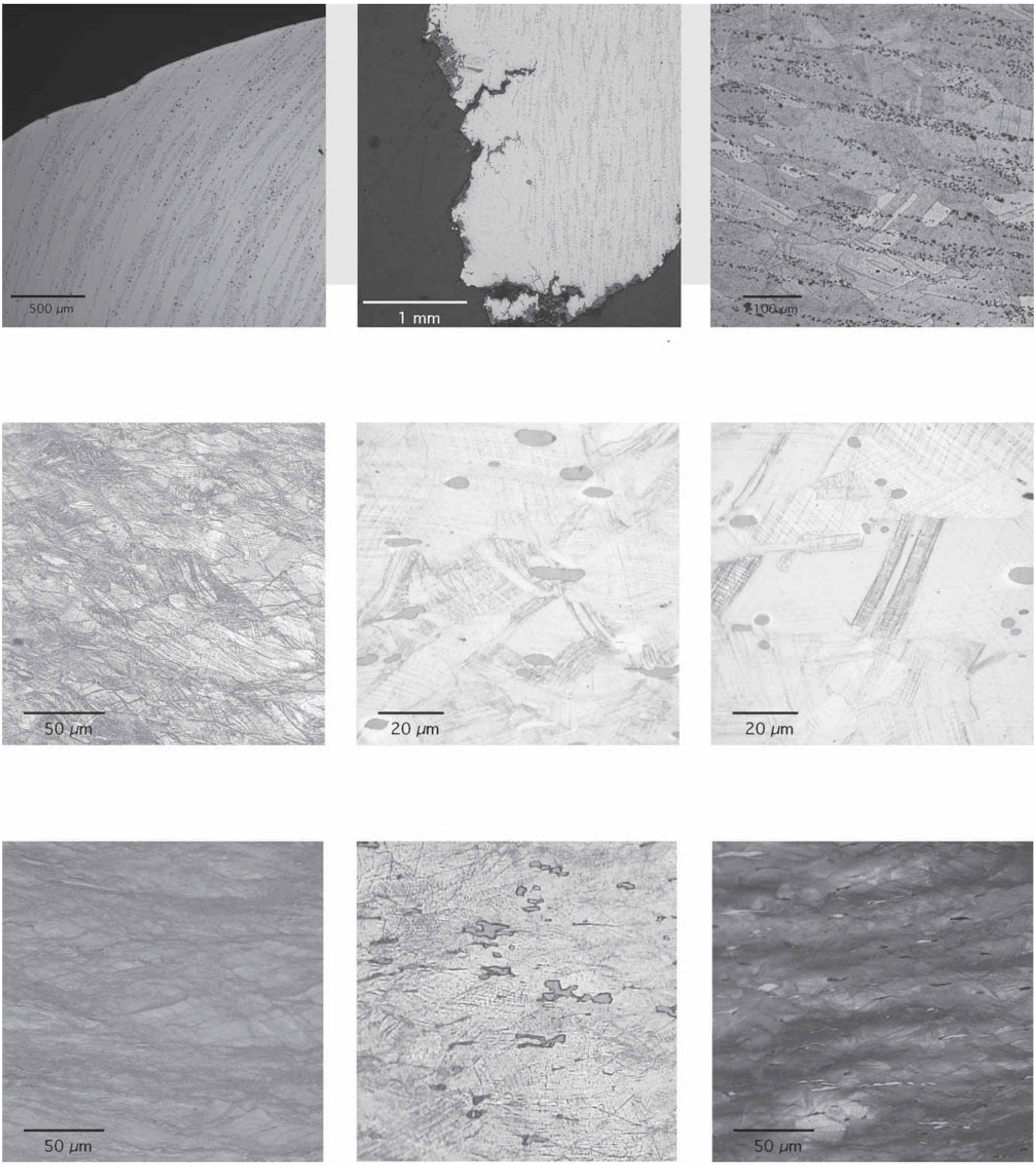
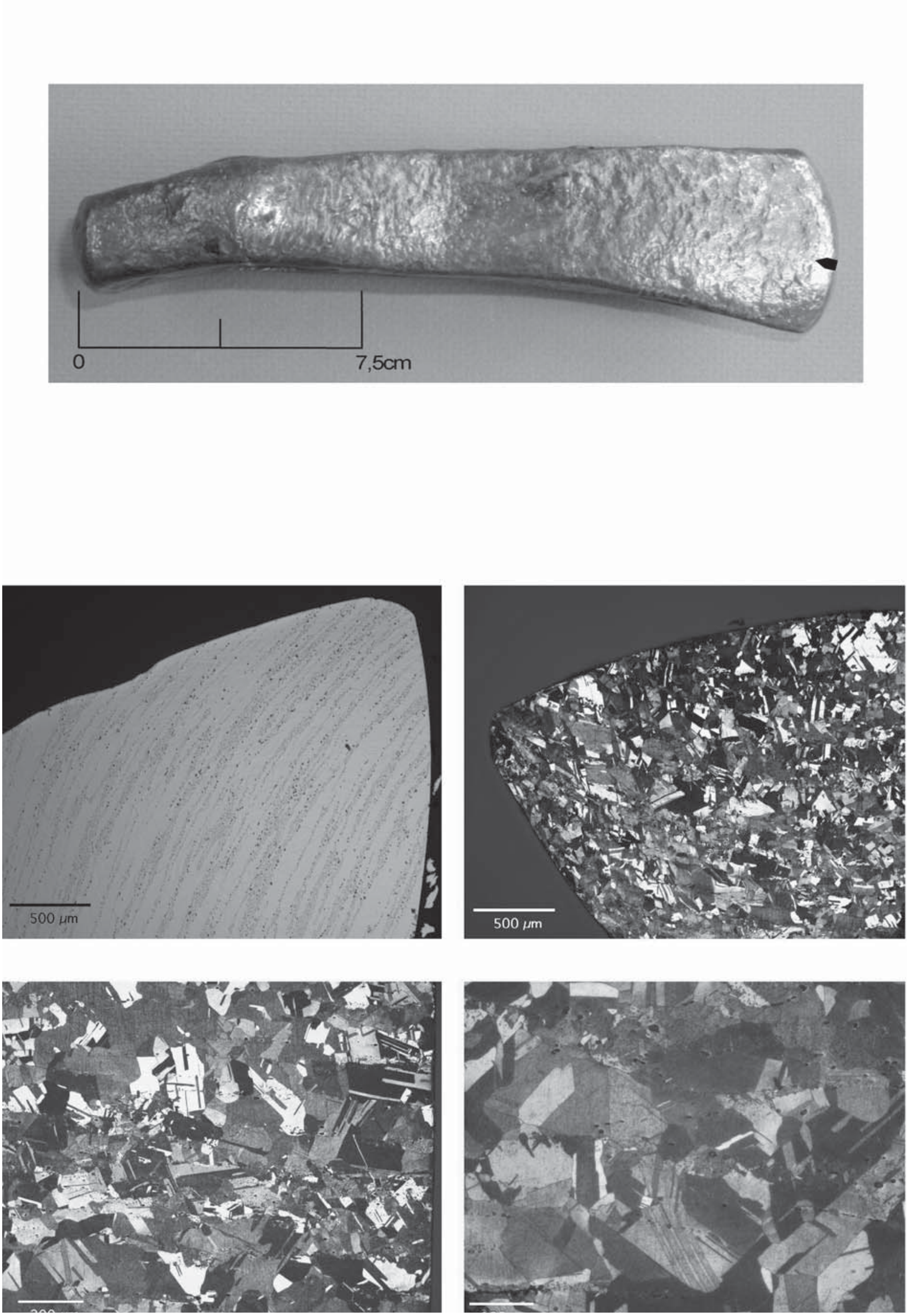


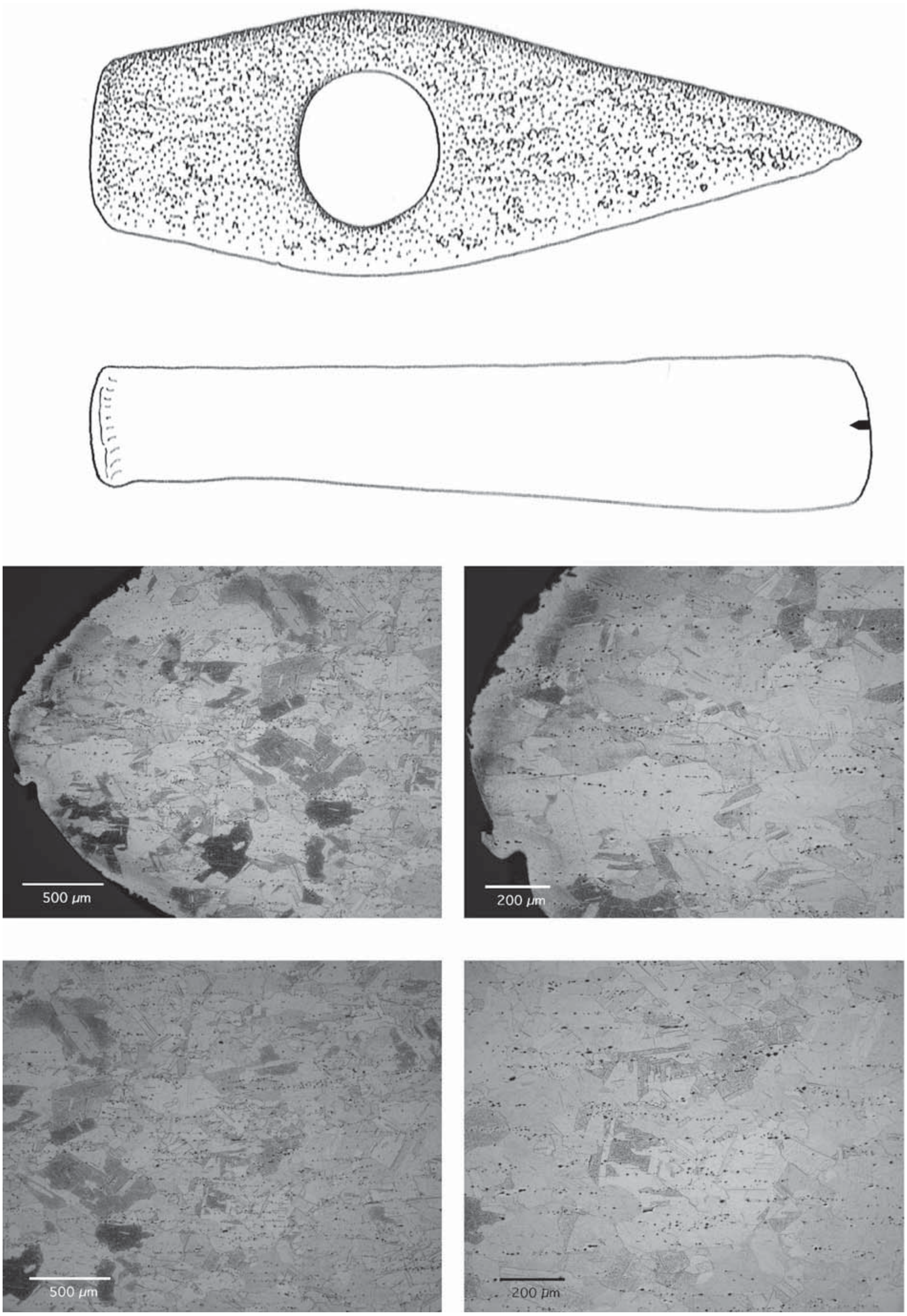
Fig. AI-19: Total reduction in thickness. Heavily deformed ($Cu+Cu_2O$)-eutectic copper oxide inclusions (top) and sulphide inlusions (middle and below) as a result of several steps of cold work.

Appendix II:
Catalogue and Tables

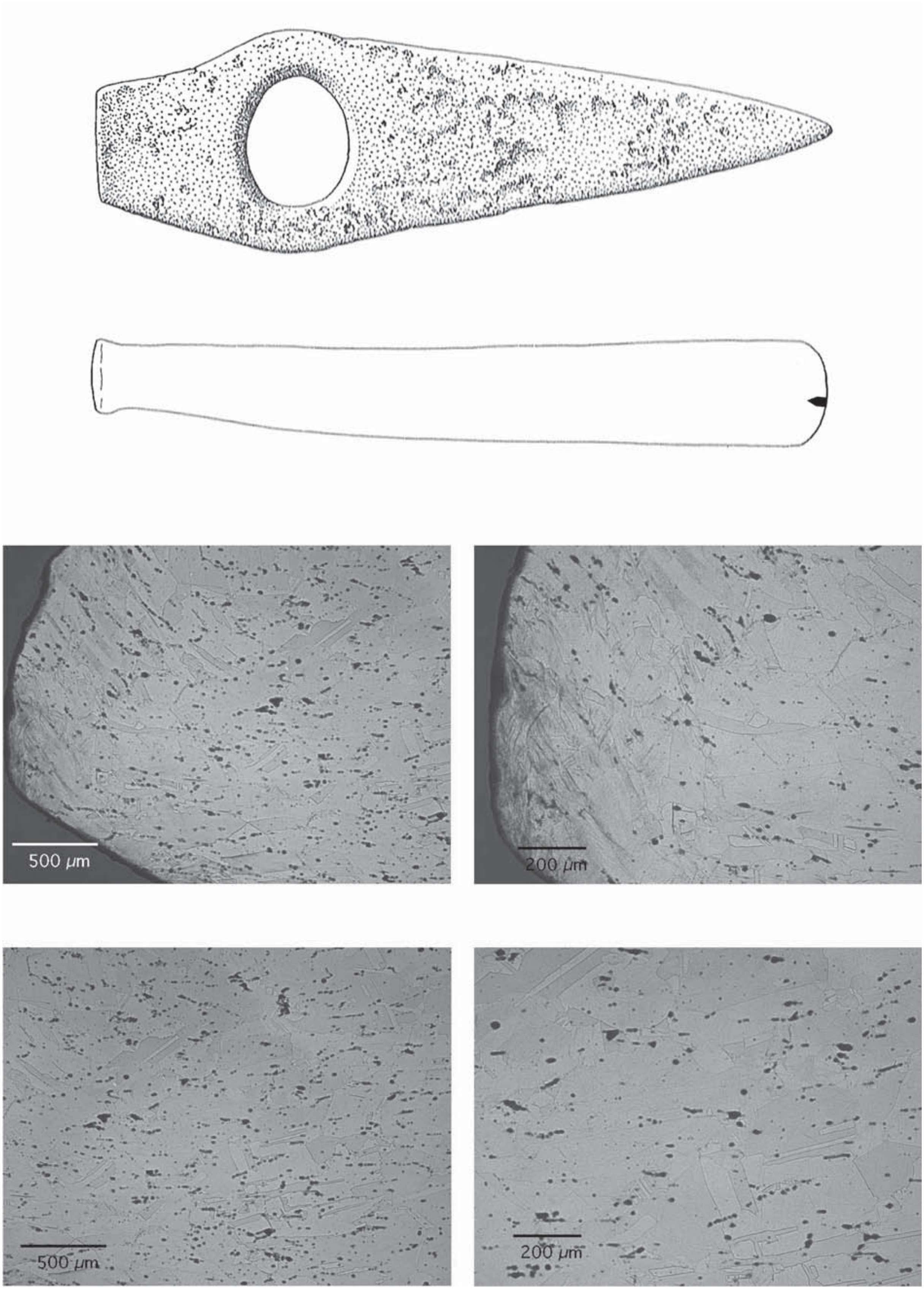
Eneolithic/Copper Age hammer axes, type Pločnik		
Sample no.	***Origin / context***	***Museum / inv. no.***
62	Bratislava? SK stray find	Bratislava, Mest. Múz., 1101 Novotná 1970, 20 no. 78
85	unknown unknown	Wien, Urgesch. Inst., 9090 Mayer 1977, 9 no. 2
100	unknown unknown	Wien, Urgesch. Inst., 9088 Mayer 1977, 9 no. 3
144	Uherské Hradiště CZ stray find	Brno, Pa 105/35 Říhovský 1992, 22 no. 3 (Gr. Ia, Typ Ia, Var. A)
153	Hodonin CZ stray find	Brno, 69505 Říhovský 1992, 22 no. 1 (Gr. Ia, Typ Ia, Var. A)
184	unknown (Danube region) unknown	Wien NHM 35048 Mayer 1977, 9 no. 4



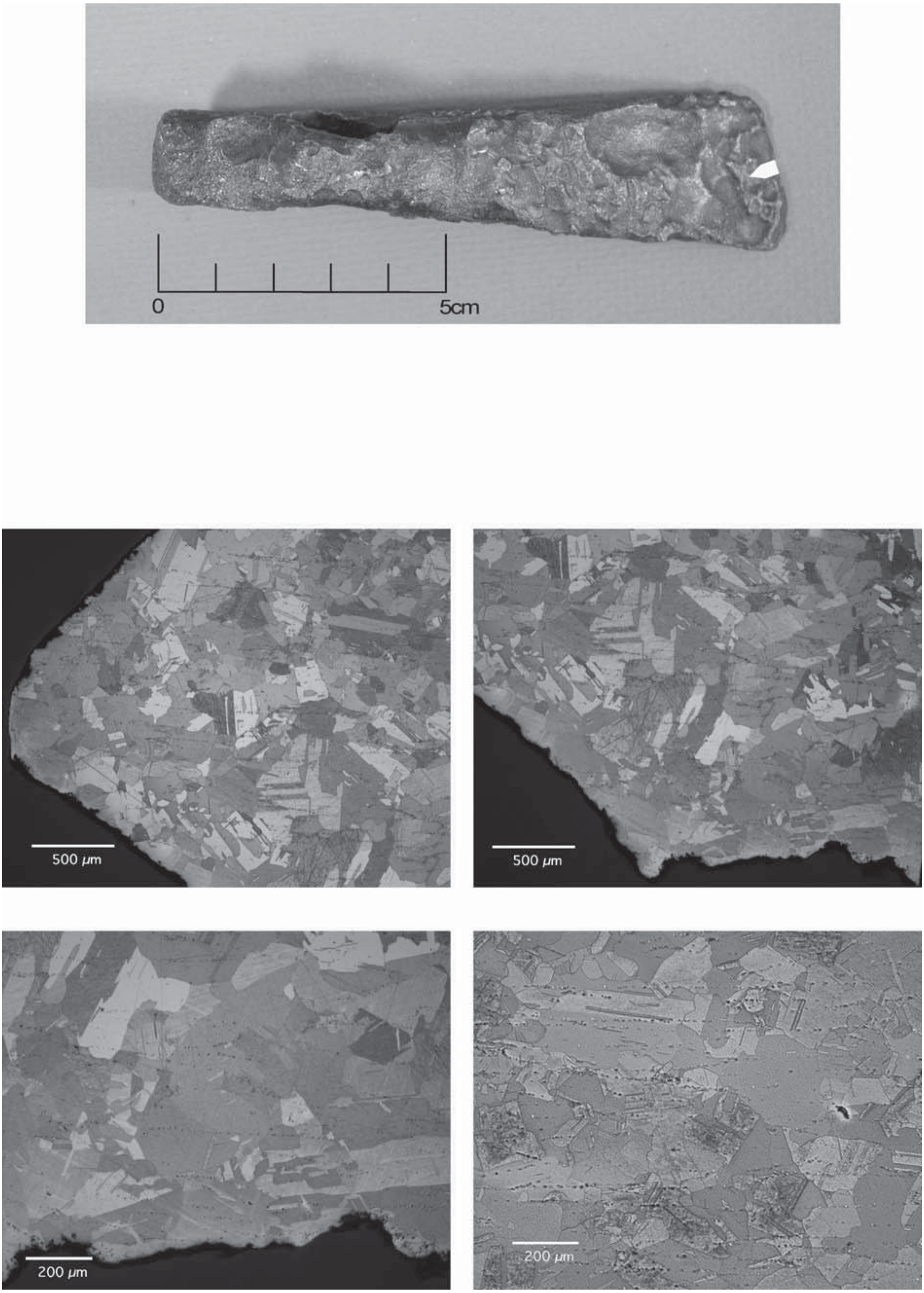
Tab. 1: Sample no. 62.



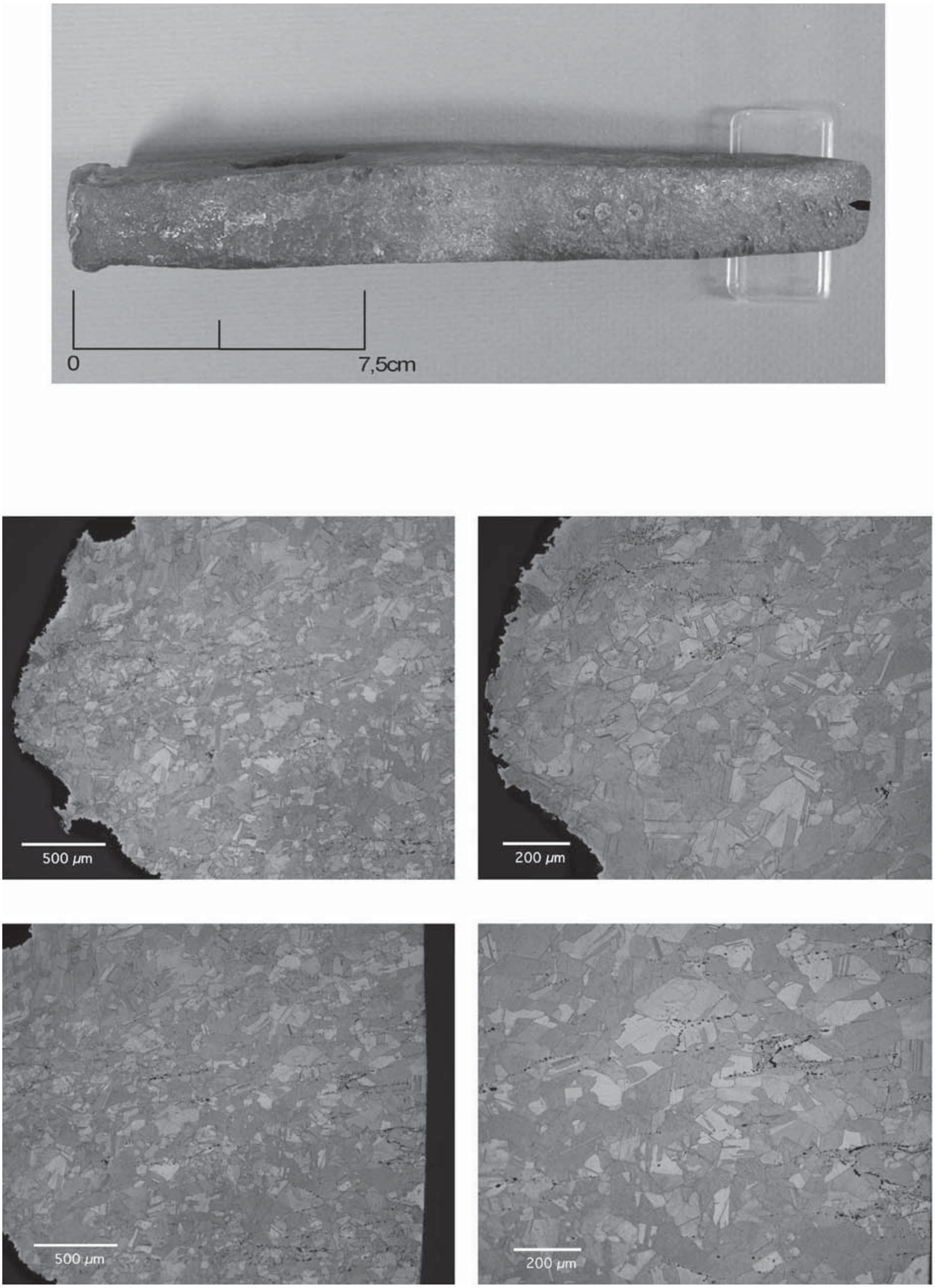
Tab. 2: Sample no. 85 (axe: 1:1).



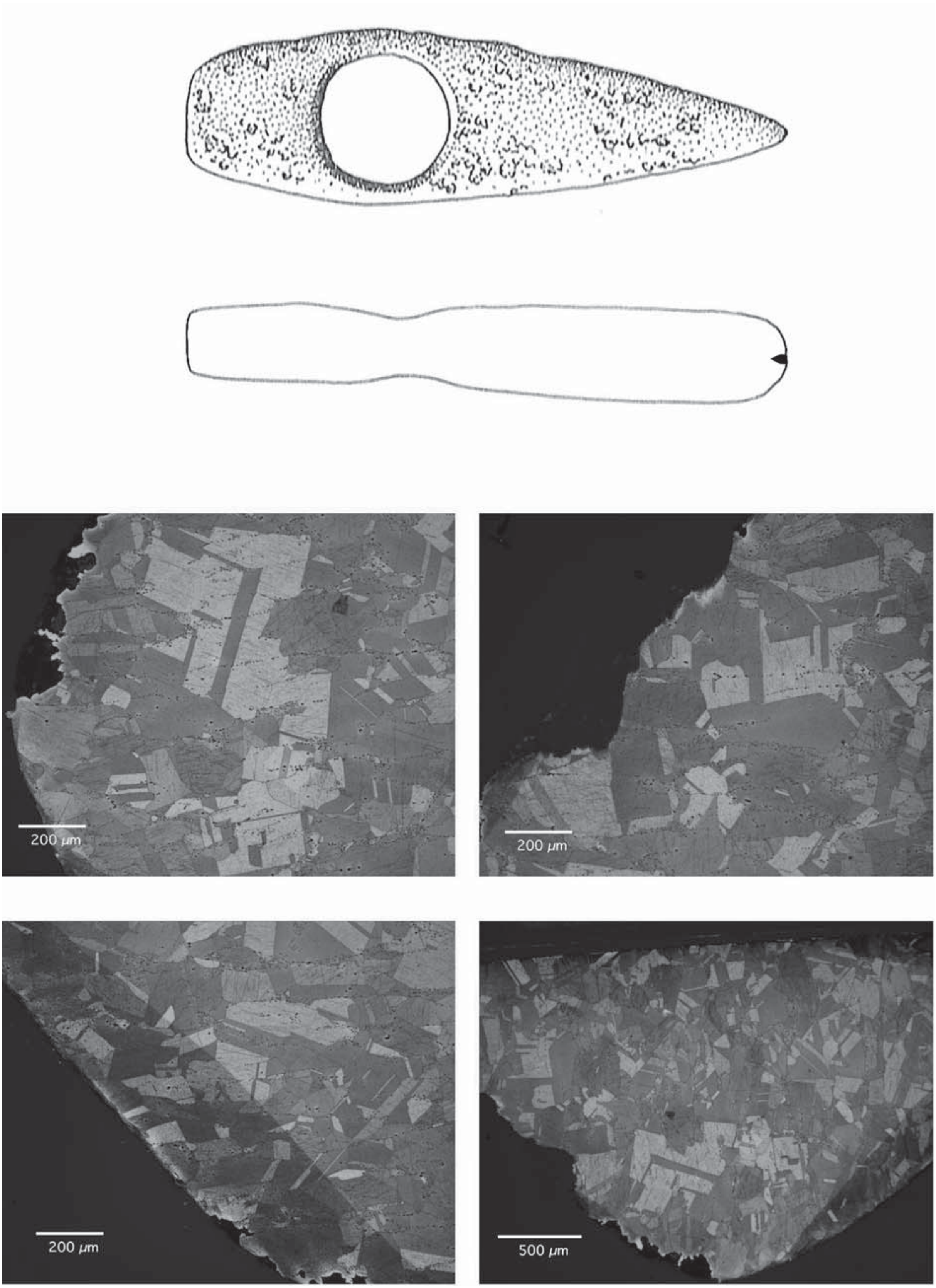
Tab. 3: Sample no. 100 (axe: 3:4).



Tab. 4: Sample no. 144.

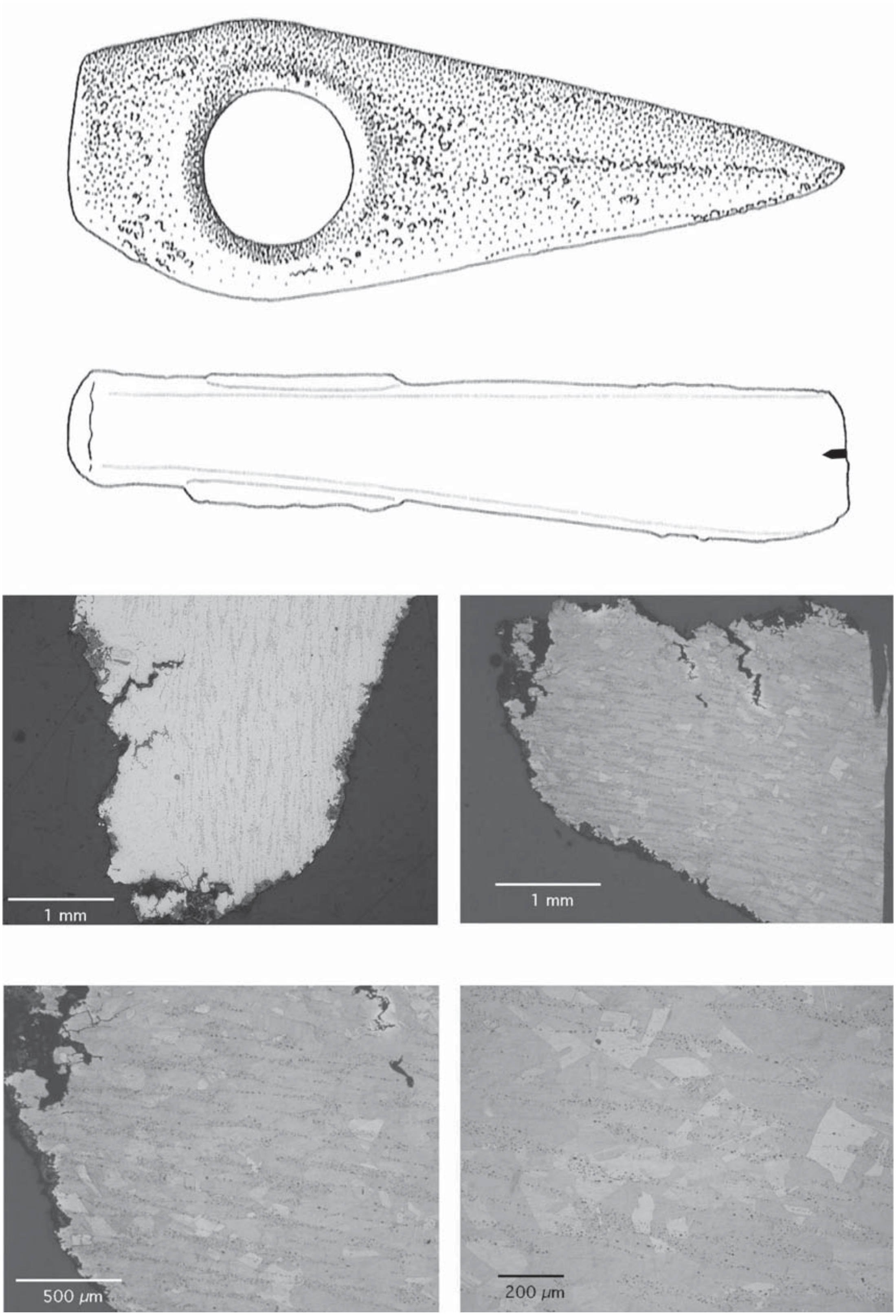


Tab. 5: Sample no. 153.



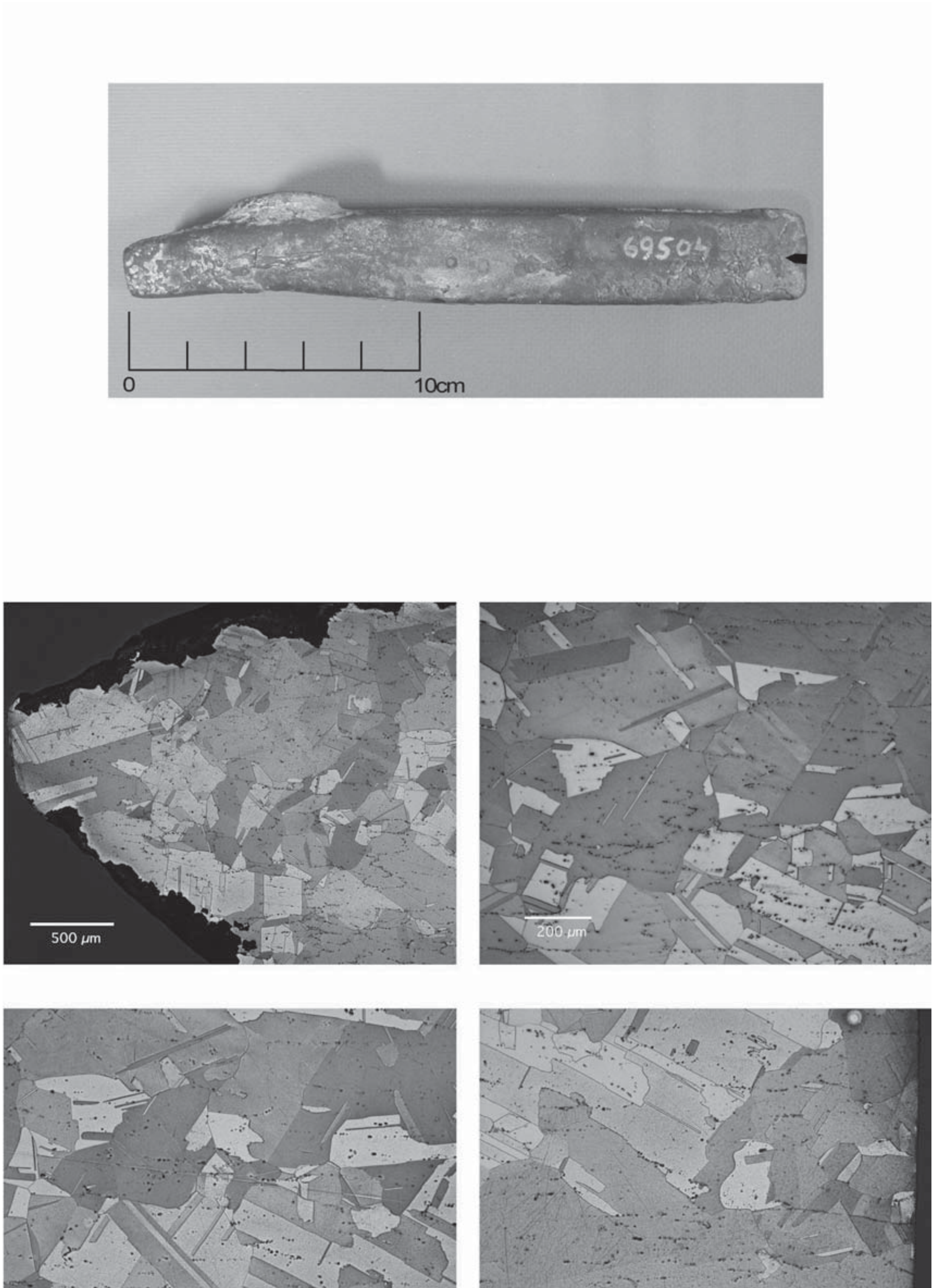
Tab. 6: Sample no. 184 (axe: 1:1).

Eneolithic/Copper Age hammer axes, type Crestur		
Sample no.	***Origin / context***	***Museum / inv. no.***
96	unknown unknown	Wien, Urgesch. Inst., 9087 Mayer 1977, 9 no. 5



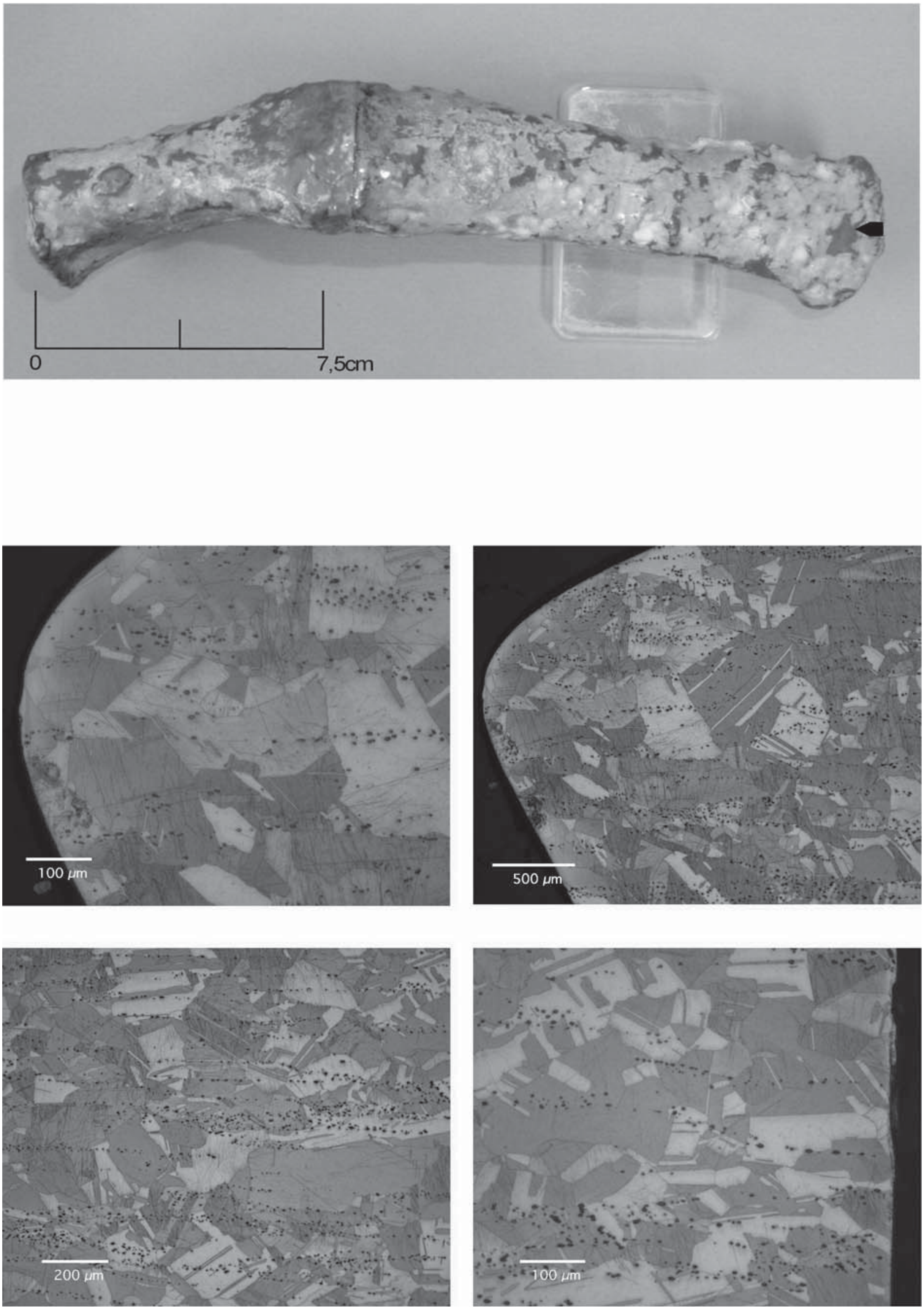
Tab. 7: Sample no. 96 (axe: 1:1).

Eneolithic/Copper Age hammer axes, type Kežmarok		
Sample no.	***Origin / context***	***Museum / inv. no.***
141	Ždánice CZ stray find	Brno, 69504 Říhovský 1992, 25 no. 7 (Gr. IIb, Typ 1b, Var. A)

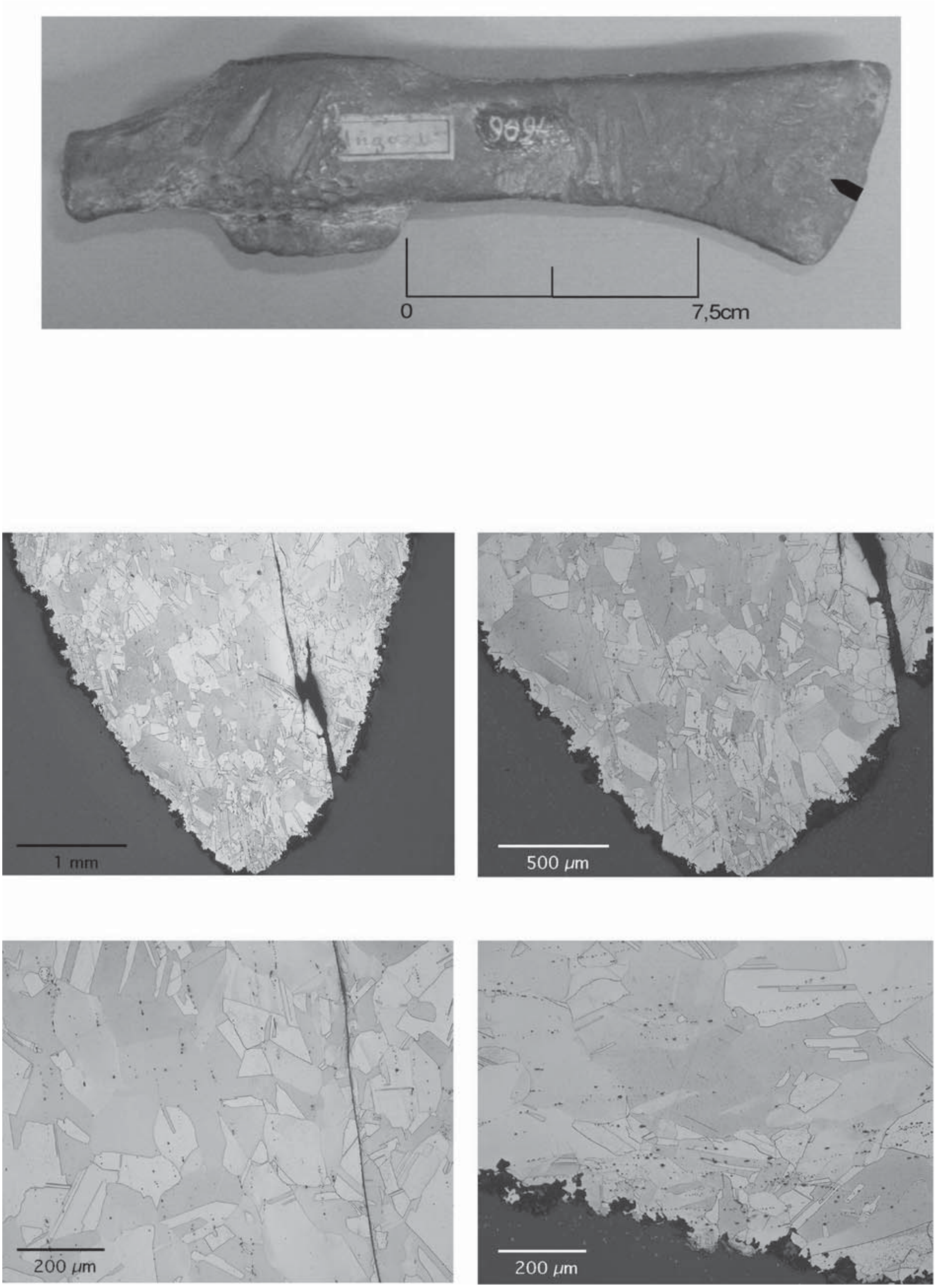


Tab. 8: Sample no. 141.

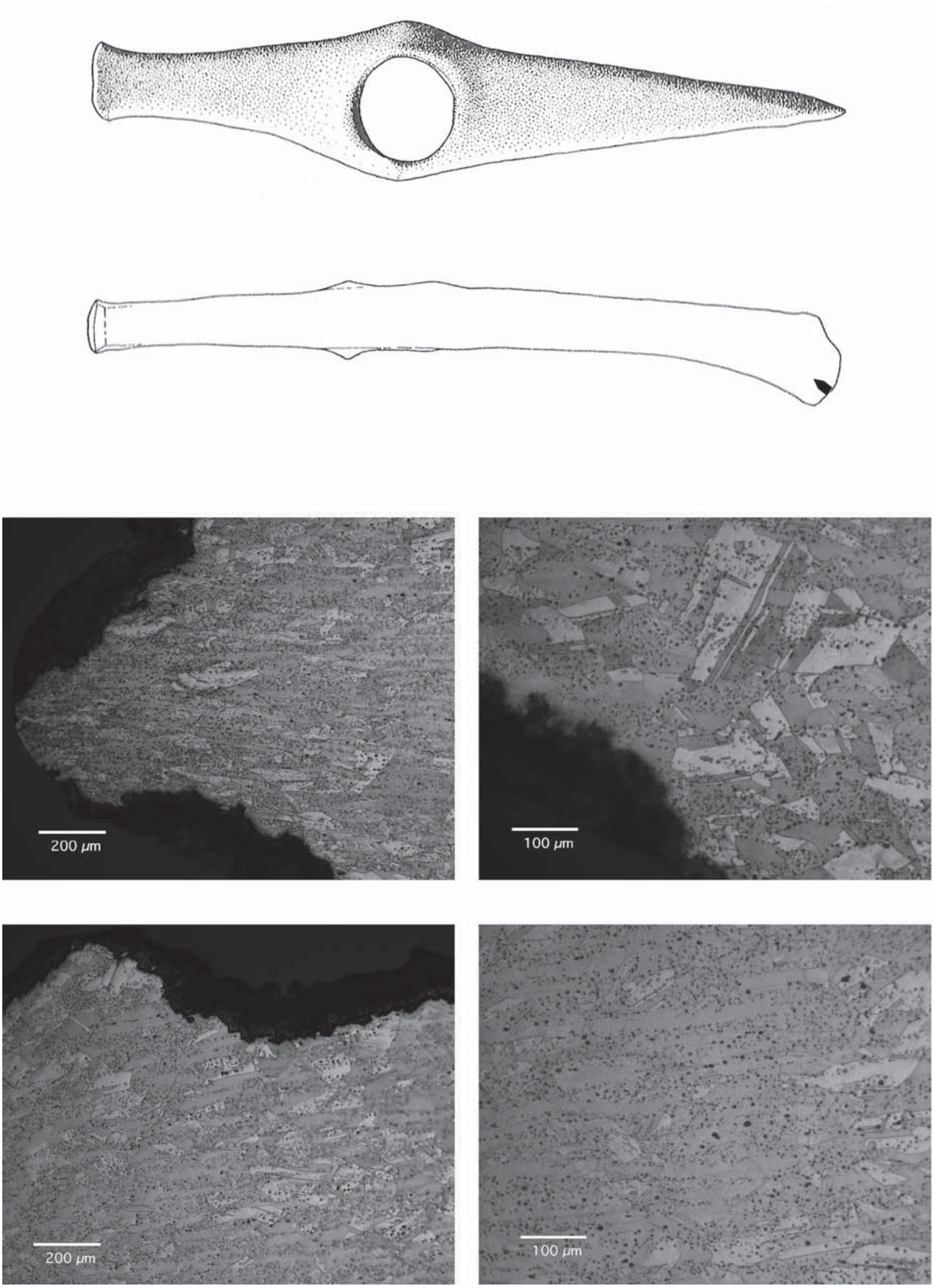
Eneolithic/Copper Age hammer axes, type Székely-Nádudvar		
Sample no.	***Origin / context***	***Museum / inv. no.***
45	Linz A hoard(?) (see sample no. 46)	Linz, A 4795 Mayer 1977, 10 no. 9
82	unknown unknown	Wien, Urgesch. Inst., 9094 Mayer 1977, 10 no. 13
176	Krottendorf / Békásmegyer (Budapest) H unknown	Wien, NHM, 28613 Patay 1984, 53 no. 246
183	Hungary unknown	Wien, NHM, 17858 Patay 1984, 51 no. 223
185	unknown (Danube region) unknown	Wien, NHM, 17860 Mayer 1977, 10 no. 12
196	Hungary unknown	Wien, NHM, 4540 Patay 1984, 52 no. 240



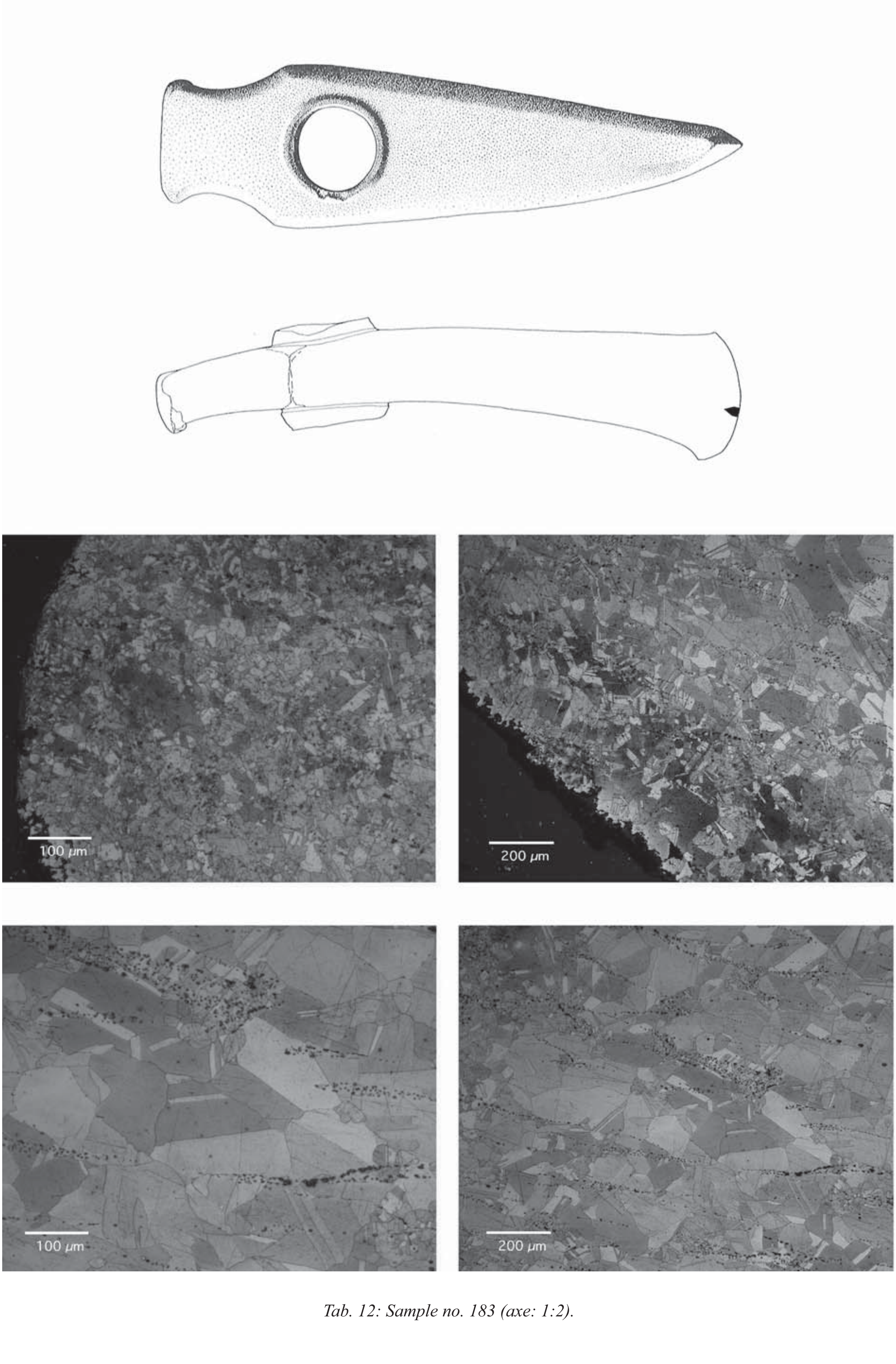
Tab. 9: Sample no. 45.



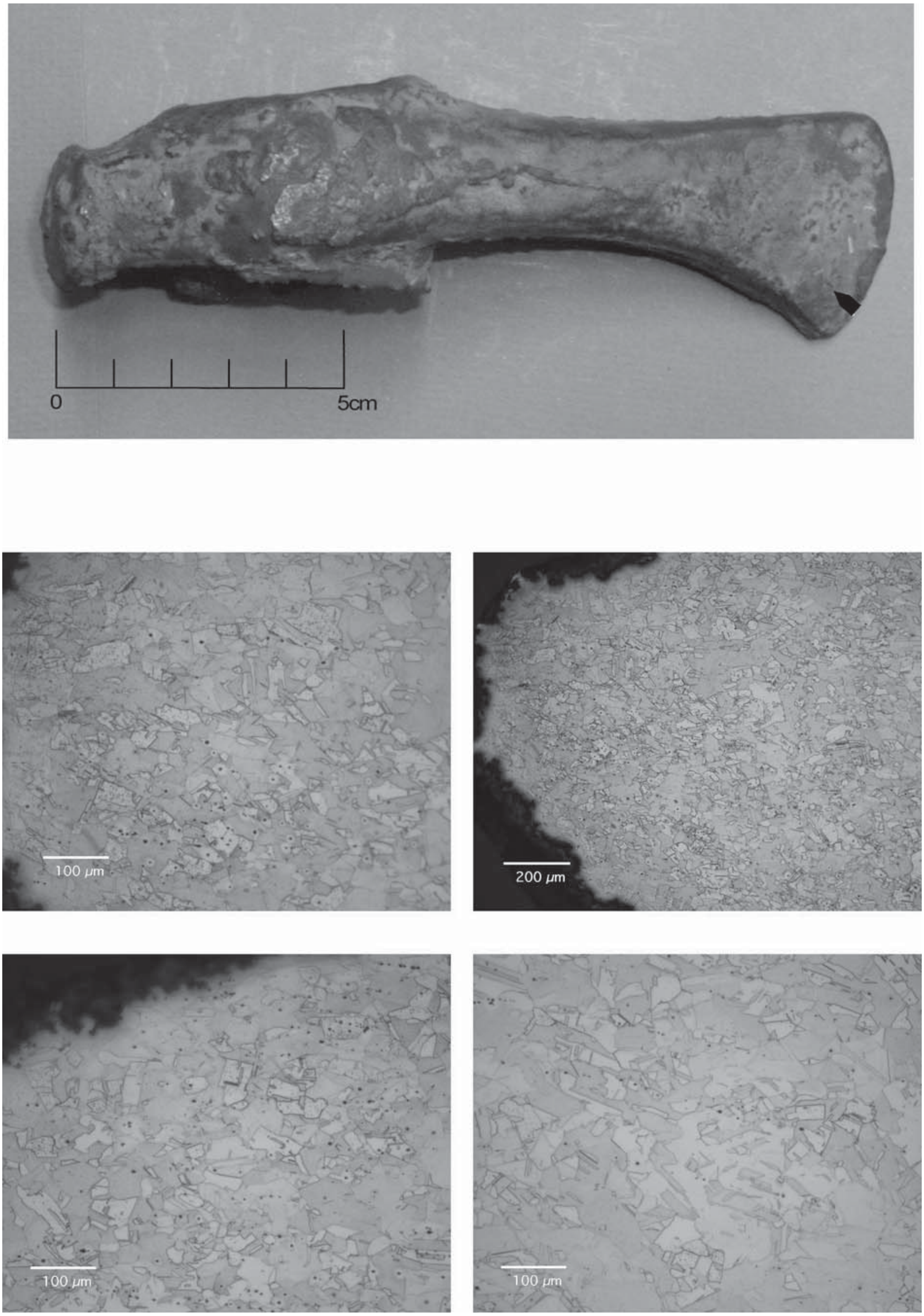
Tab. 10: Sample no. 82.



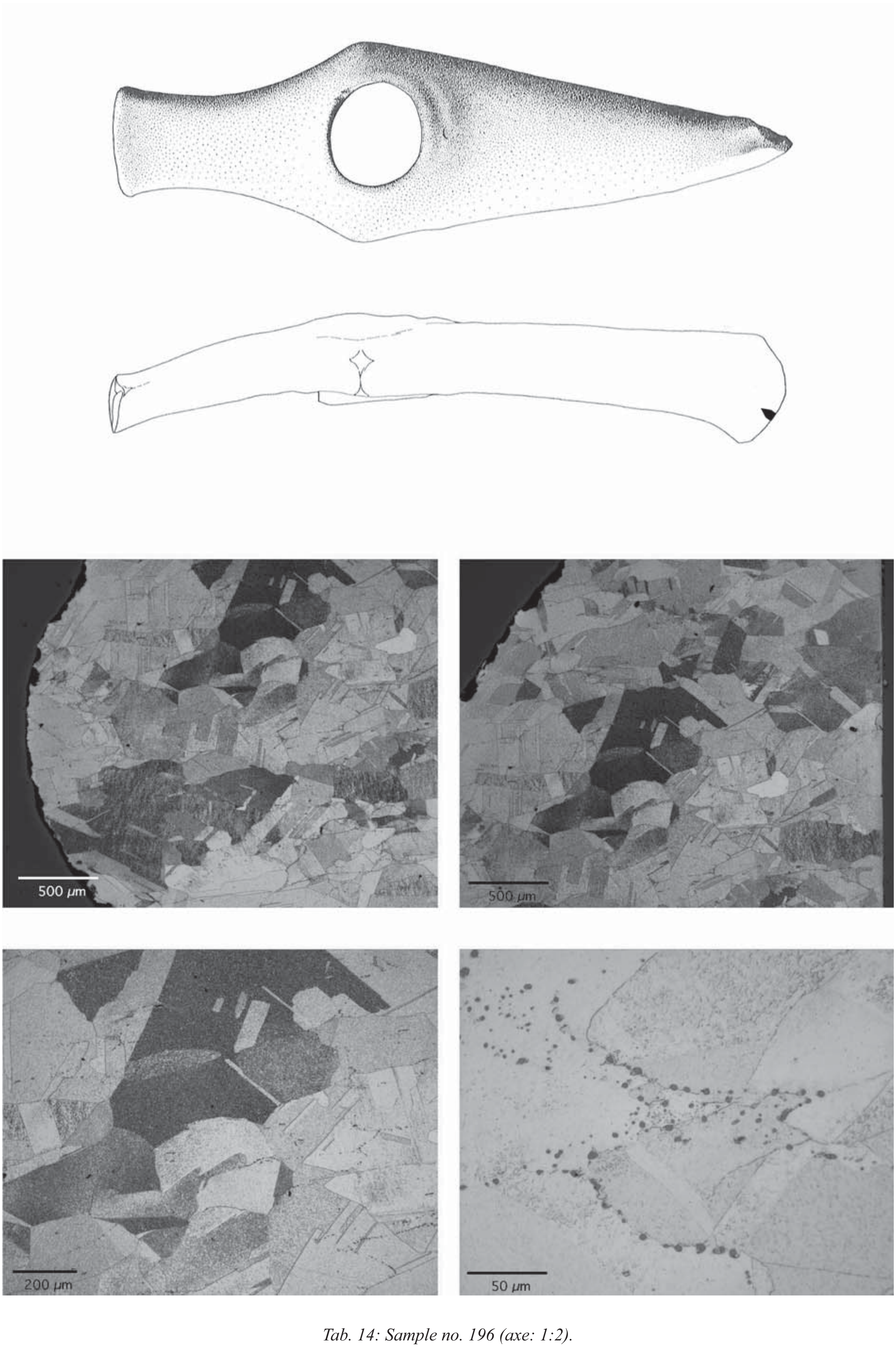
Tab. 11: Sample no. 176 (axe: 3:4).



Tab. 12: Sample no. 183 (axe: 1:2).

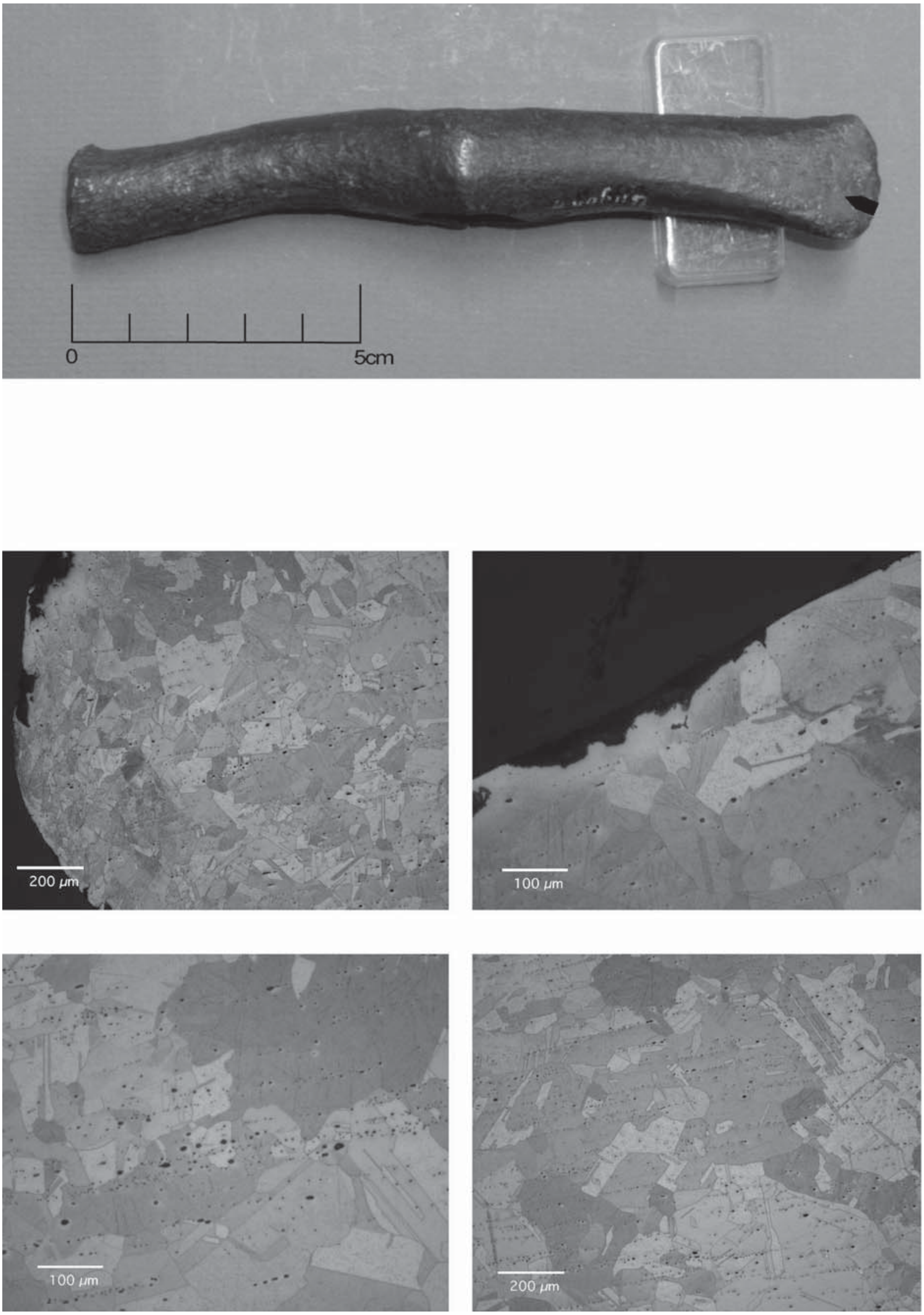


Tab. 13: Sample no. 185.

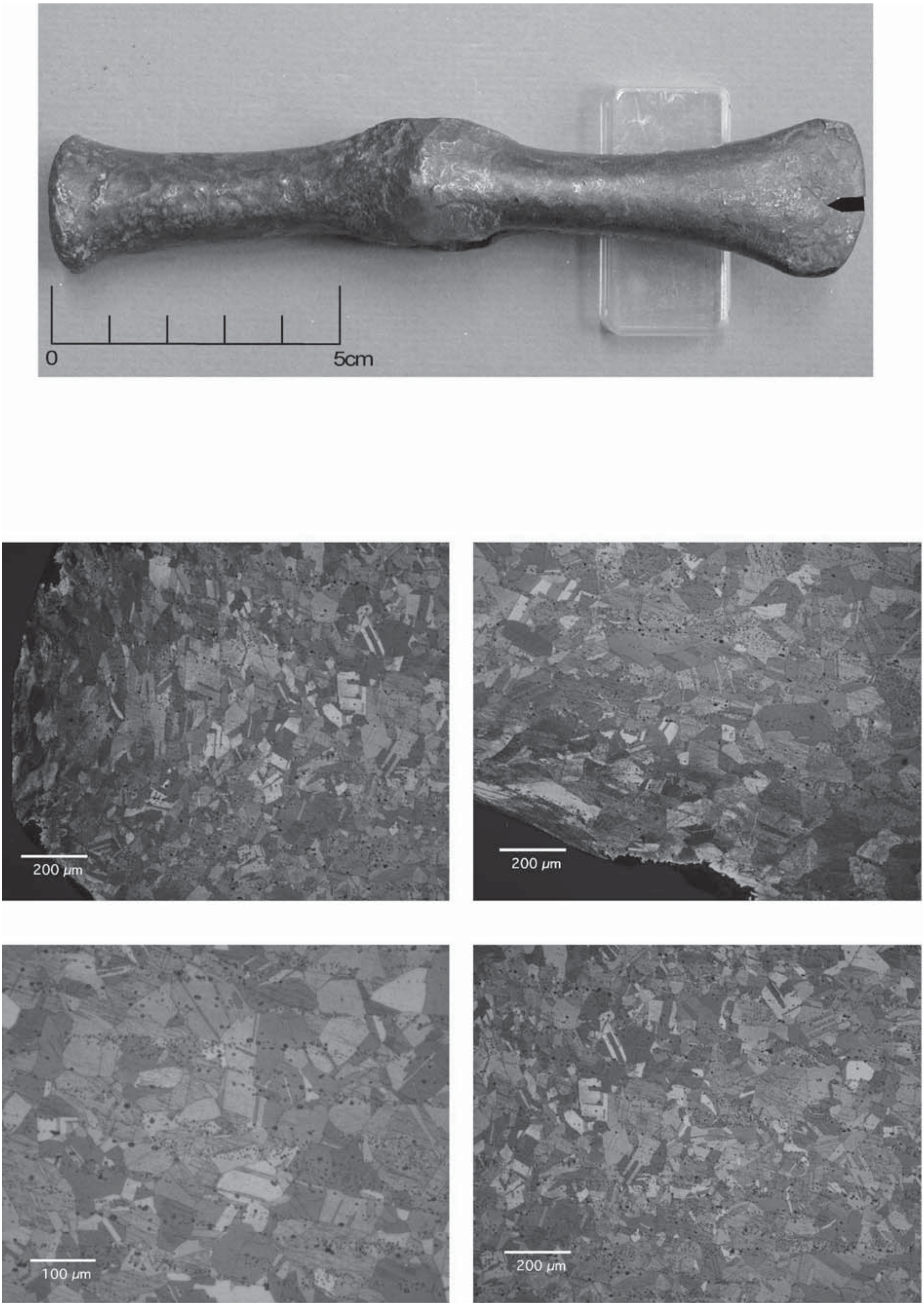


Tab. 14: Sample no. 196 (axe: 1:2).

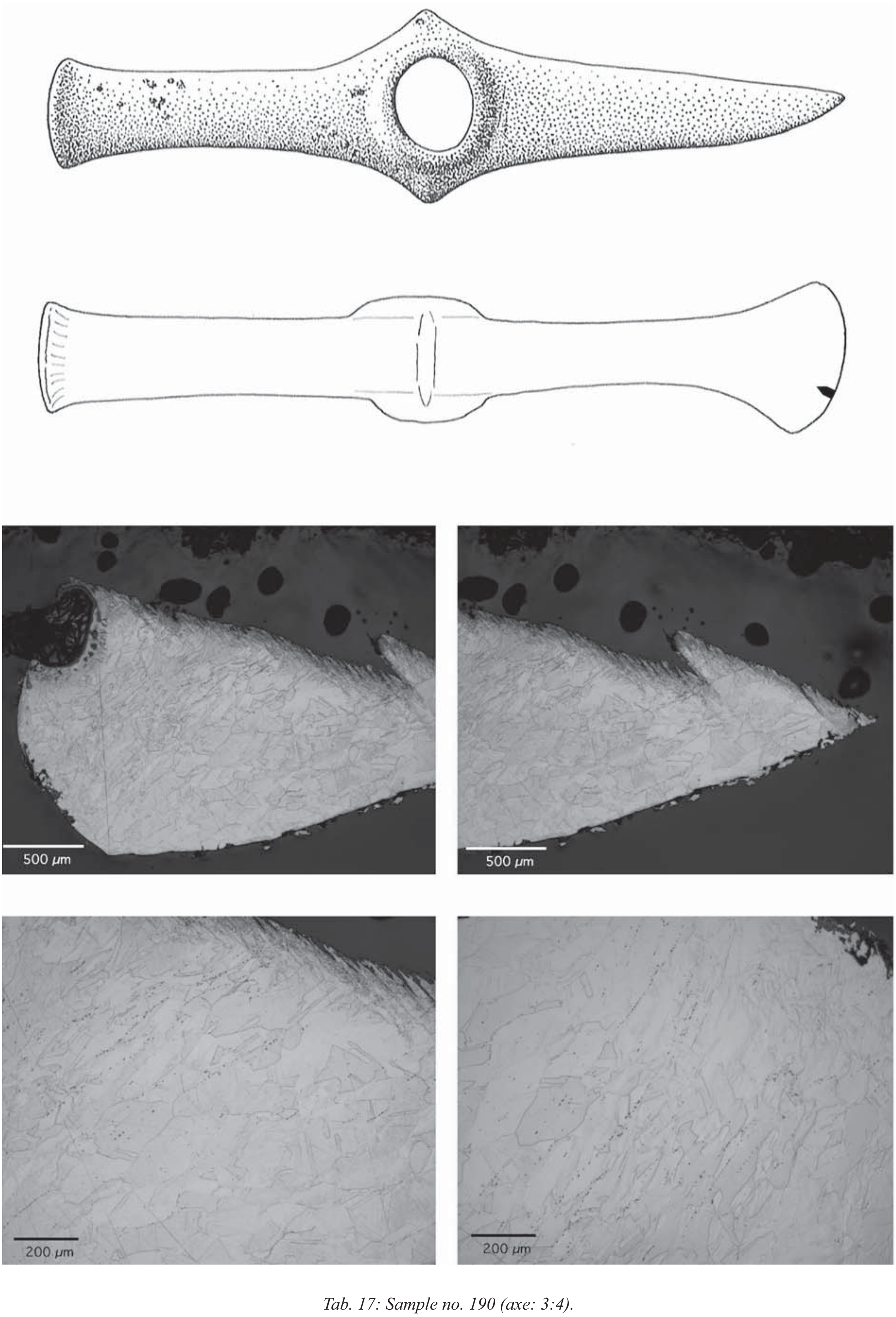
Eneolithic/Copper Age hammer axes, type Şiria		
Sample no.	***Origin / context***	***Museum / inv. no.***
181	Hungary unknown	Wien, NHM, 17861 Patay 1984, 64 no. 286
182	Komárom (surroundings) H unknown	Wien, NHM, 28398 Patay 1984, 65 no. 299 / Mayer 1977, 11 no. 18
190	unknown (Danube region) unknown	Wien, NHM, 35047 Mayer 1977, 11 no. 19



Tab. 15: Sample no. 181.

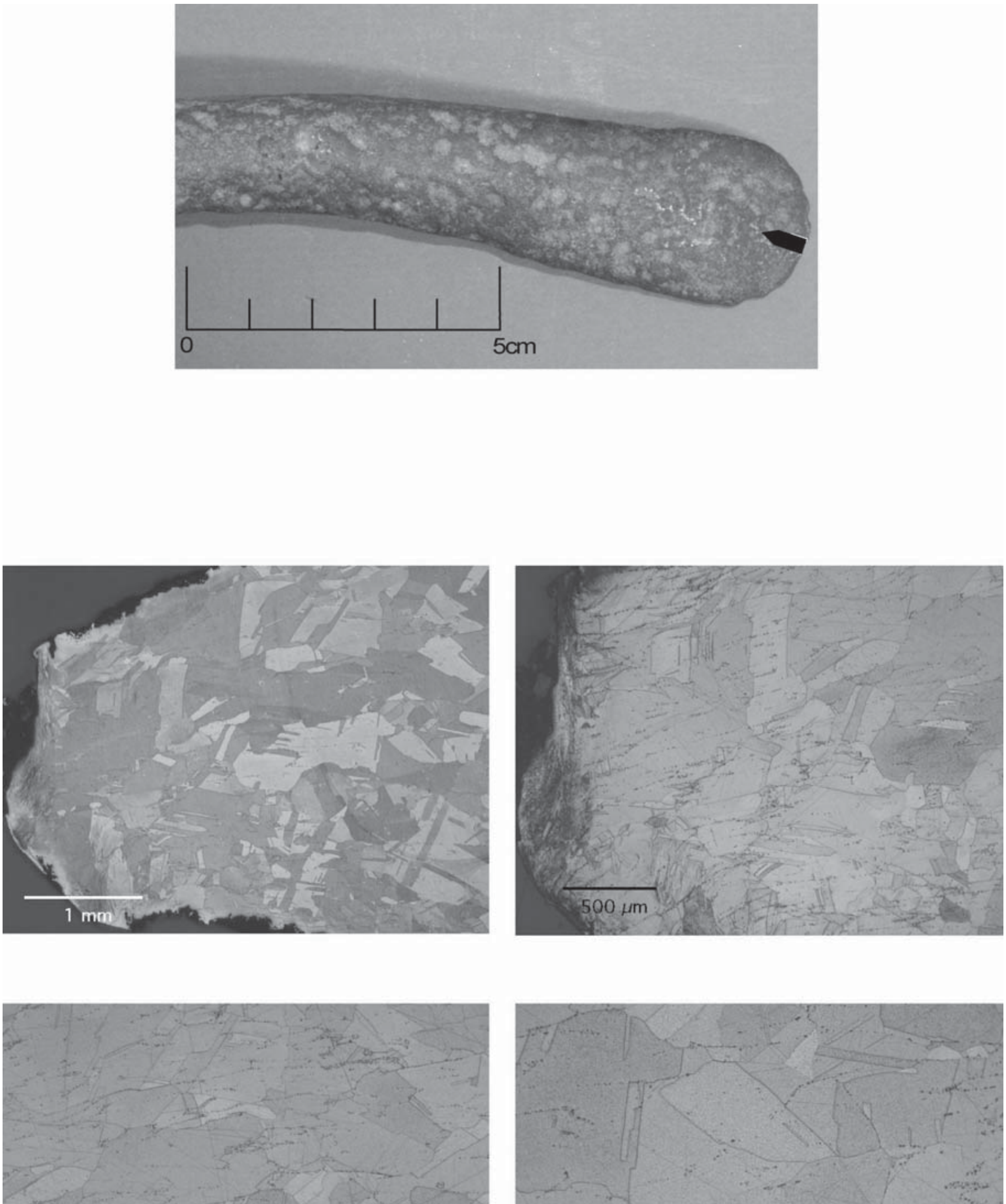


Tab. 16: Sample no. 182.

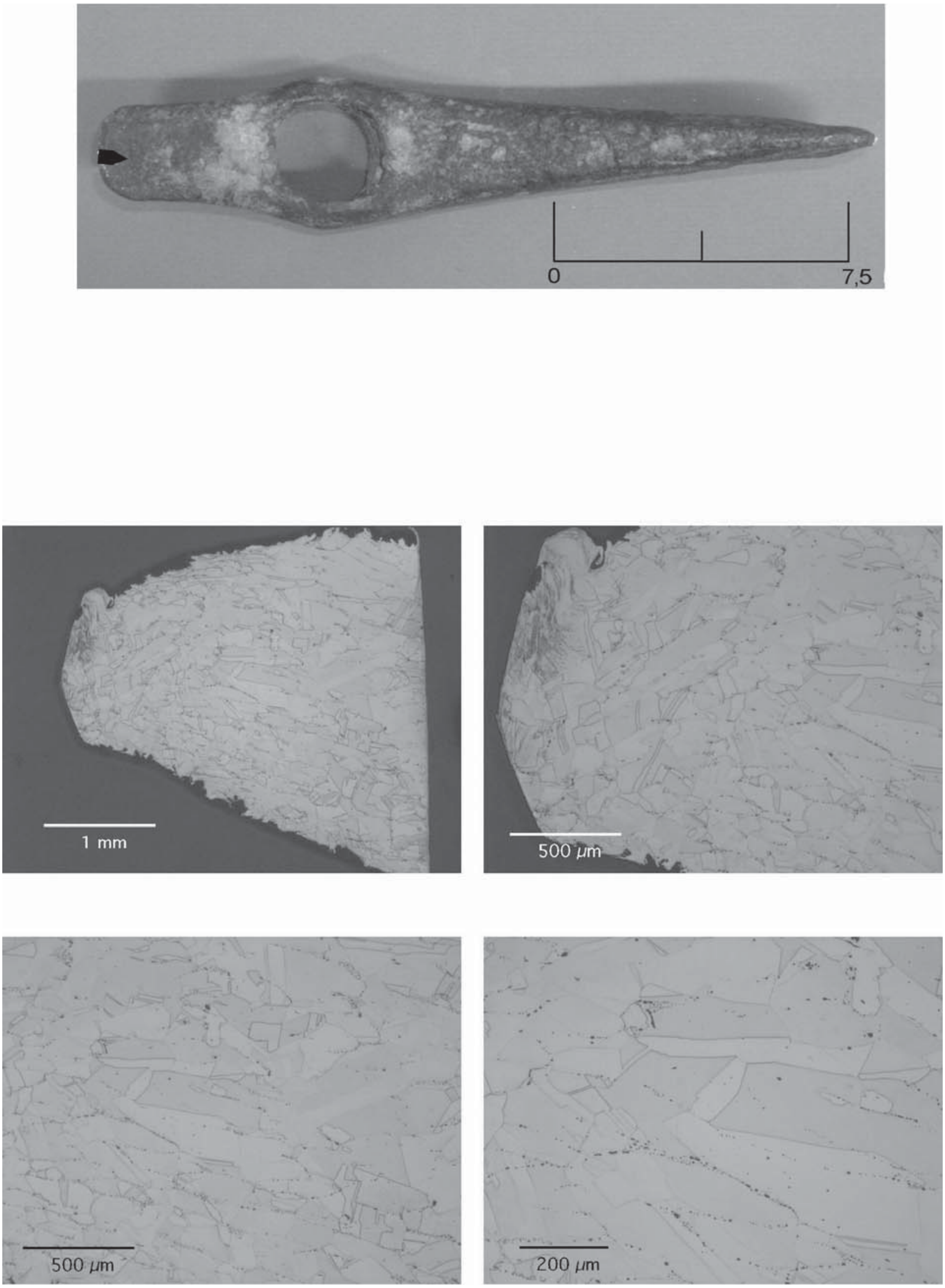


Tab. 17: Sample no. 190 (axe: 3:4).

Eneolithic/Copper Age axe-adzes, type Mugeni/Ariuşd		
Sample no.	***Origin / context***	***Museum / inv. no.***
91-1/-2	unknown unknown	Wien, Urgesch. Inst., 9103 Mayer 1977, 11 no. 22

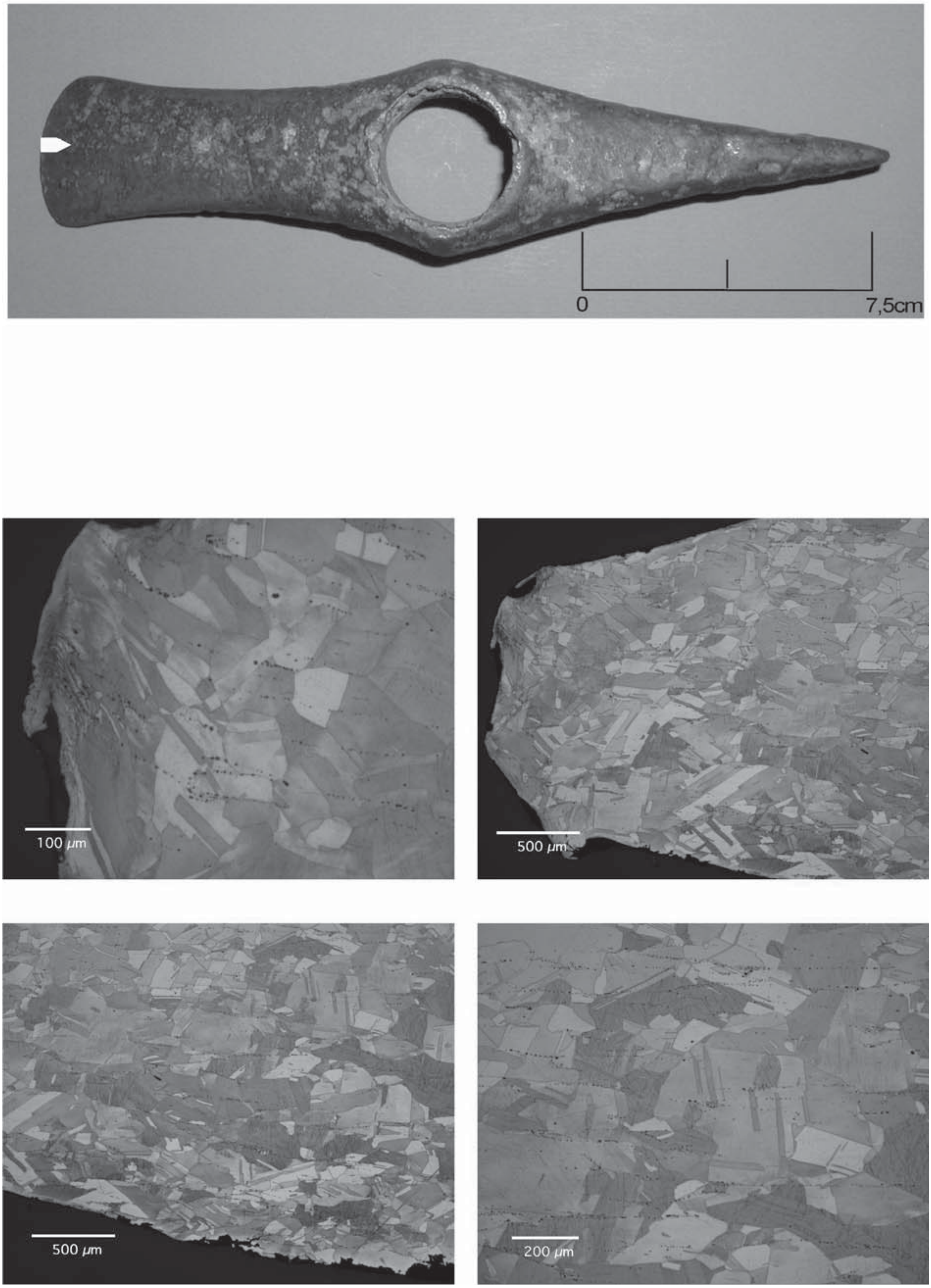


Tab. 18-1: Sample no. 91-1.

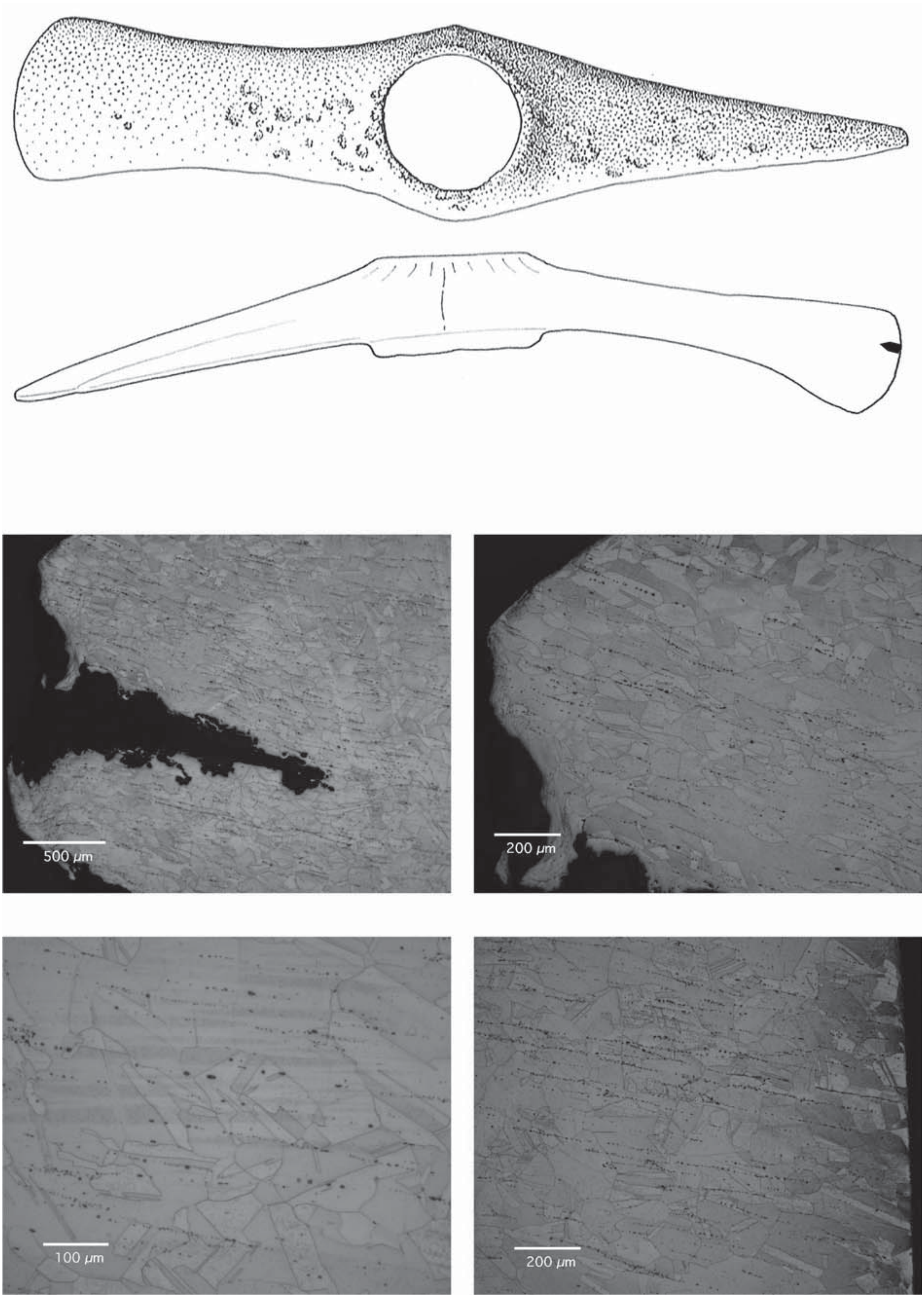


Tab. 18-2: Sample no. 91-2.

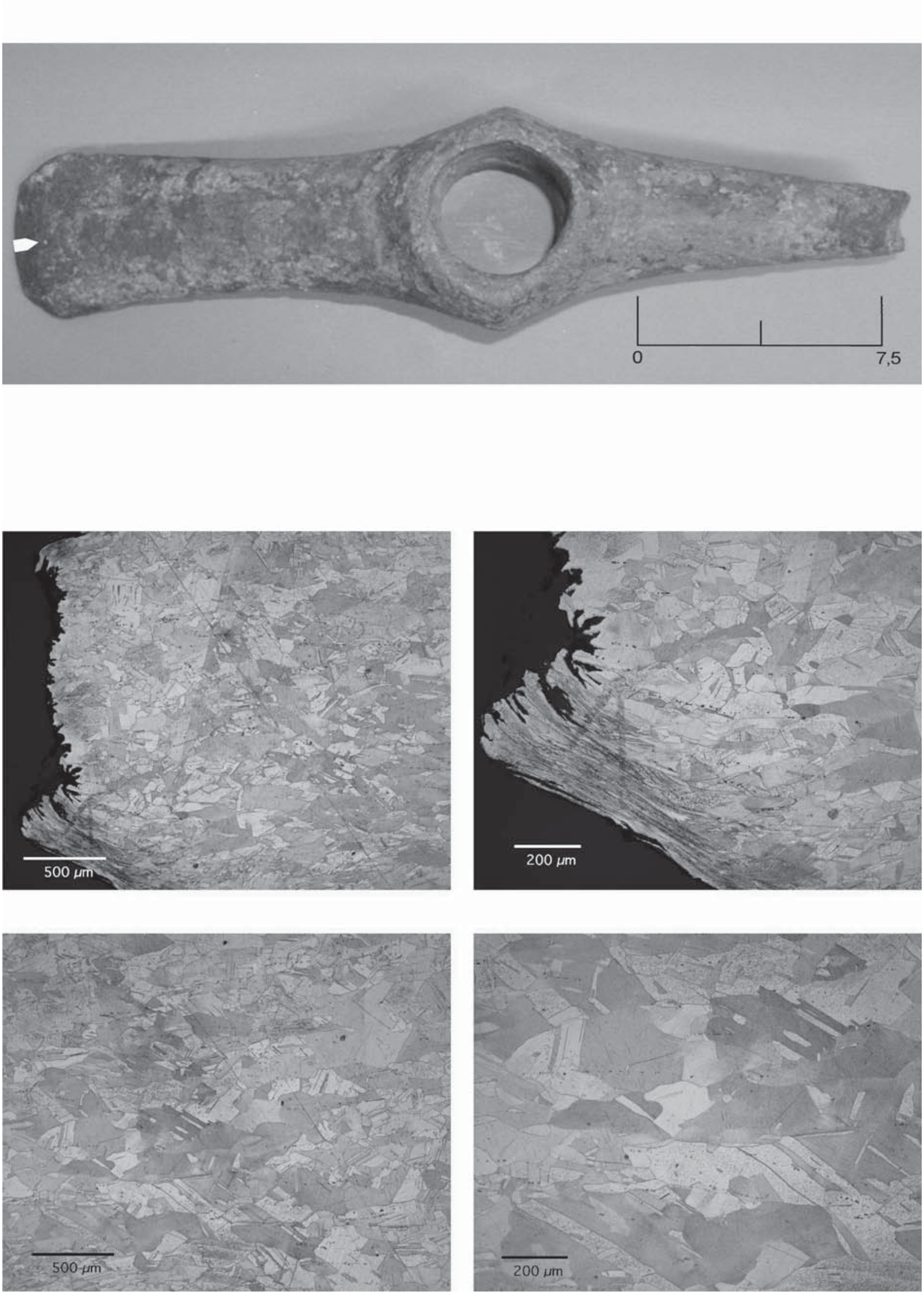
Eneolithic/Copper Age axe-adzes, type Jászladány		
Sample no.	***Origin / context***	***Museum / inv. no.***
48-1/-2	unknown unknown	Linz A 3137 Mayer 1977, 12 no. 26
98	unknown unknown	Wien, Urgesch. Inst., 9100 Mayer 1977, 12 no. 28
105-1/-2	unknown unknown	Wien, Urgesch. Inst., 9098 Mayer 1977, 12 no. 25
107-1/-2		Wien, Institut 9097
138-1/-2	Plaveč(?) SK unknown	Brno 69500 Říhovský 1992, 34 no. 23 (Gruppe IId, Typ 3c, Var. E/E)
175-1/-2	Hungary unknown	Wien, NHM, 17866 Patay 1984, 71 no. 335
177-1/-2	unknown (Danube region) unknown	Wien, NHM, 35043 Mayer 1977, 12 no. 27
178-1/-2	Hungary unknown	Wien, NHM, 4539 Patay 1984, 79 no. 428
179	Hungary unknown	Wien, NHM, 40265 Patay 1984, 76 no. 389
189	Moravia / Northern Hungary	Wien, NHM, 34319
205-1/-2	Sopron-Bánfalva H unknown	Wien, NHM, 20984 Patay 1984, 75 no. 385
206-1/-2	Hungary unknown	Wien, NHM, 11283 Patay 1984, 74 no. 372



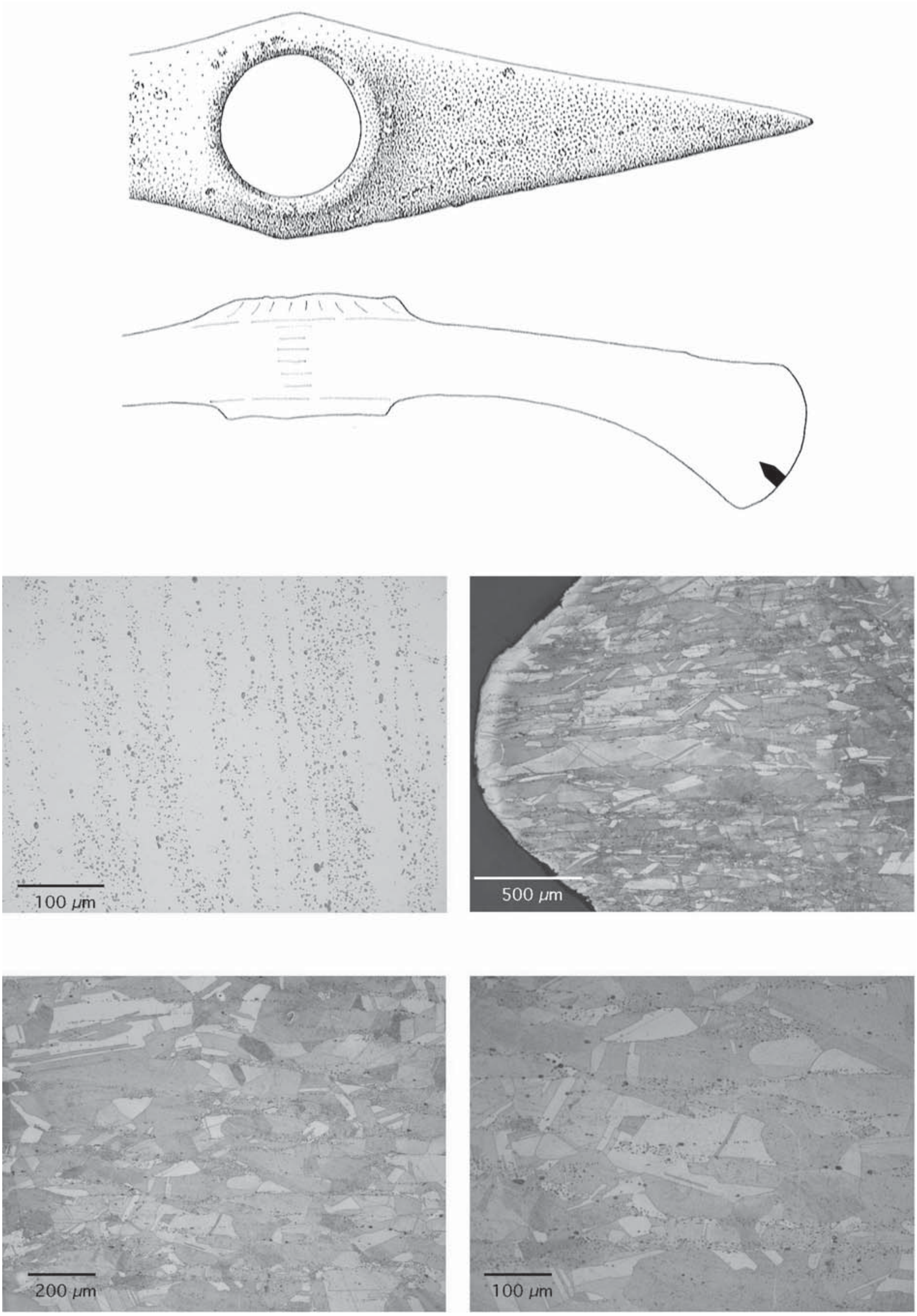
Tab. 19-1: Sample no. 48-1.



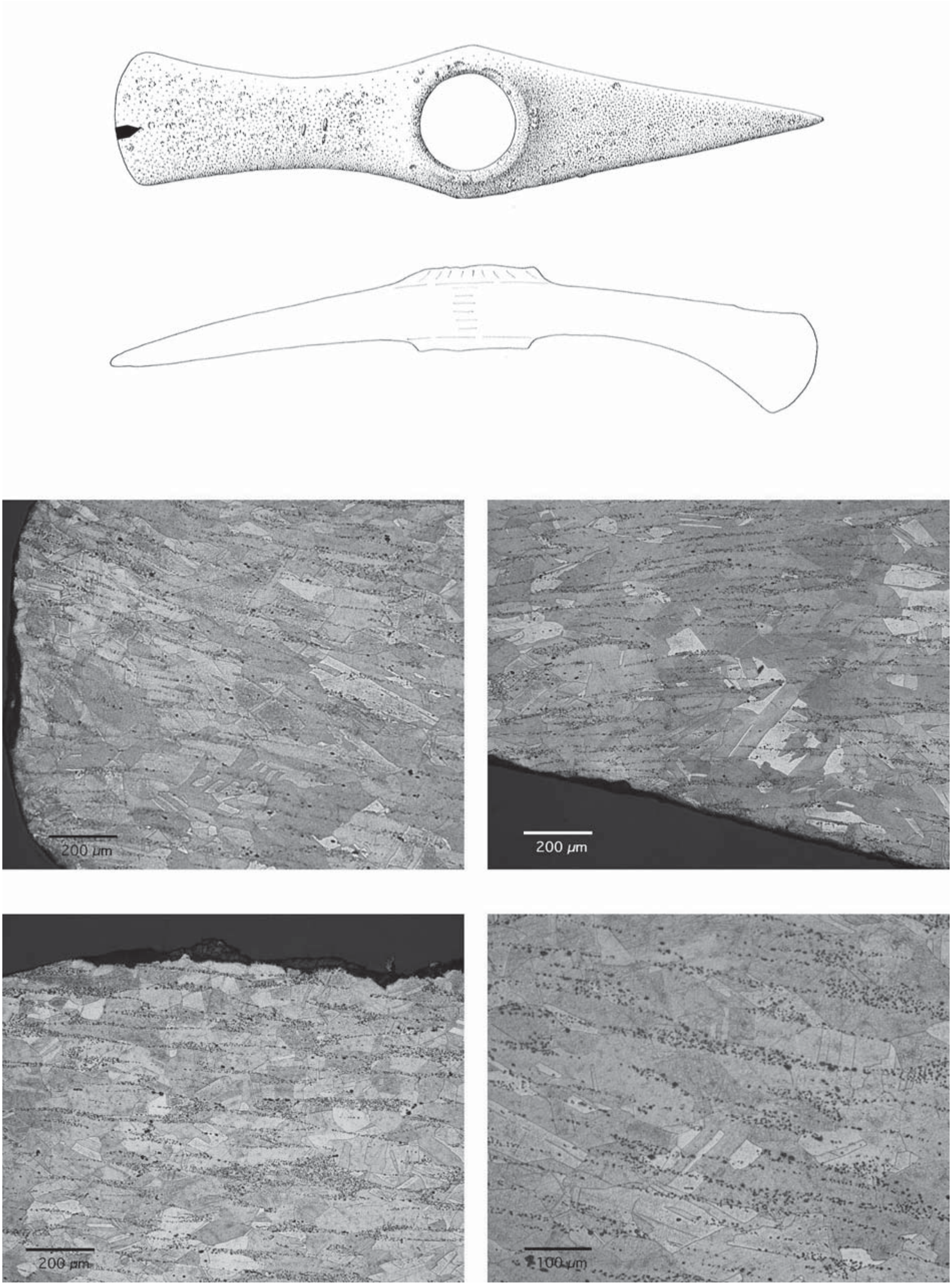
Tab. 19-2: Sample no. 48-2 (axe: 3:4).



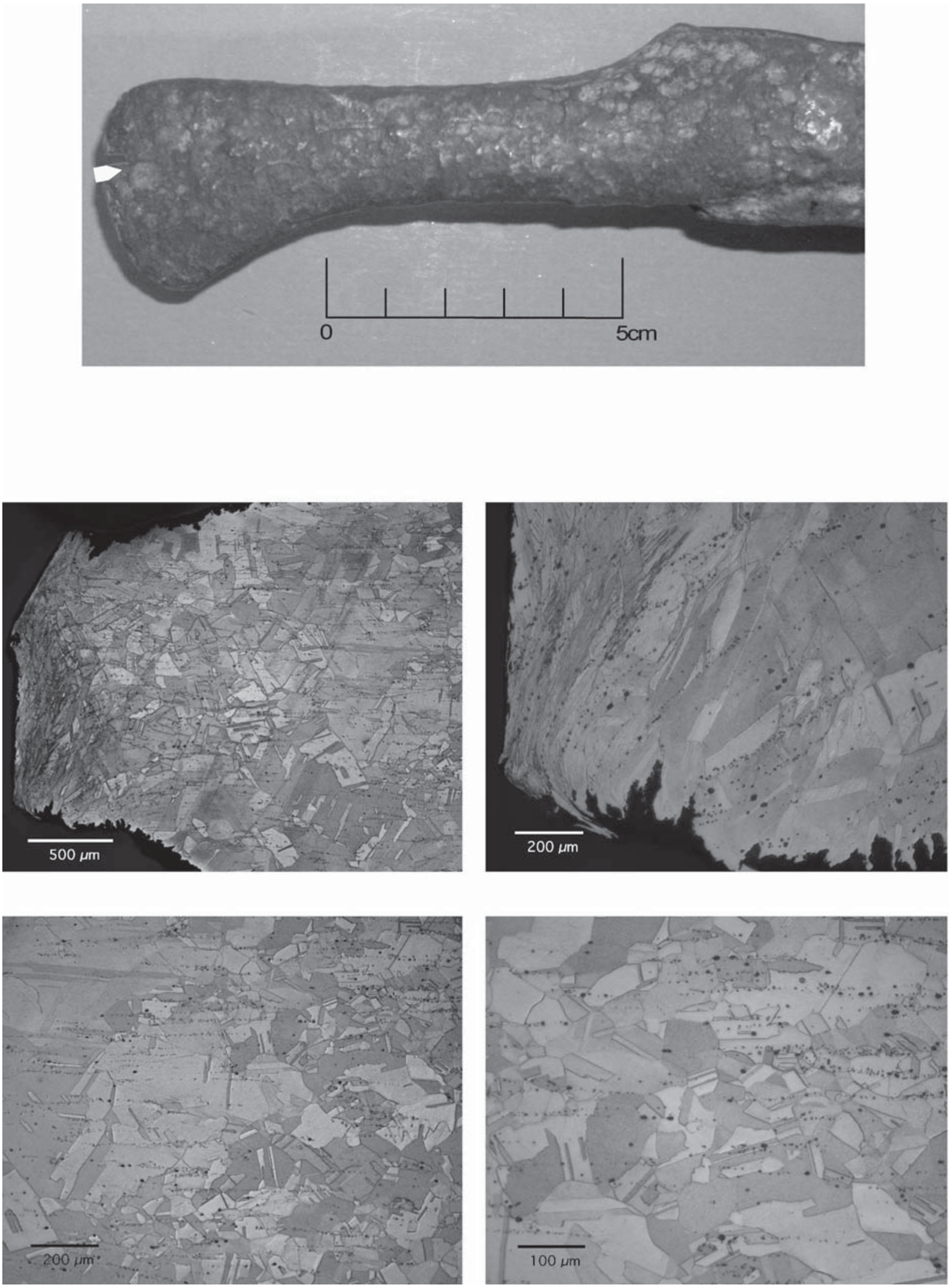
Tab. 20: Sample no. 98.



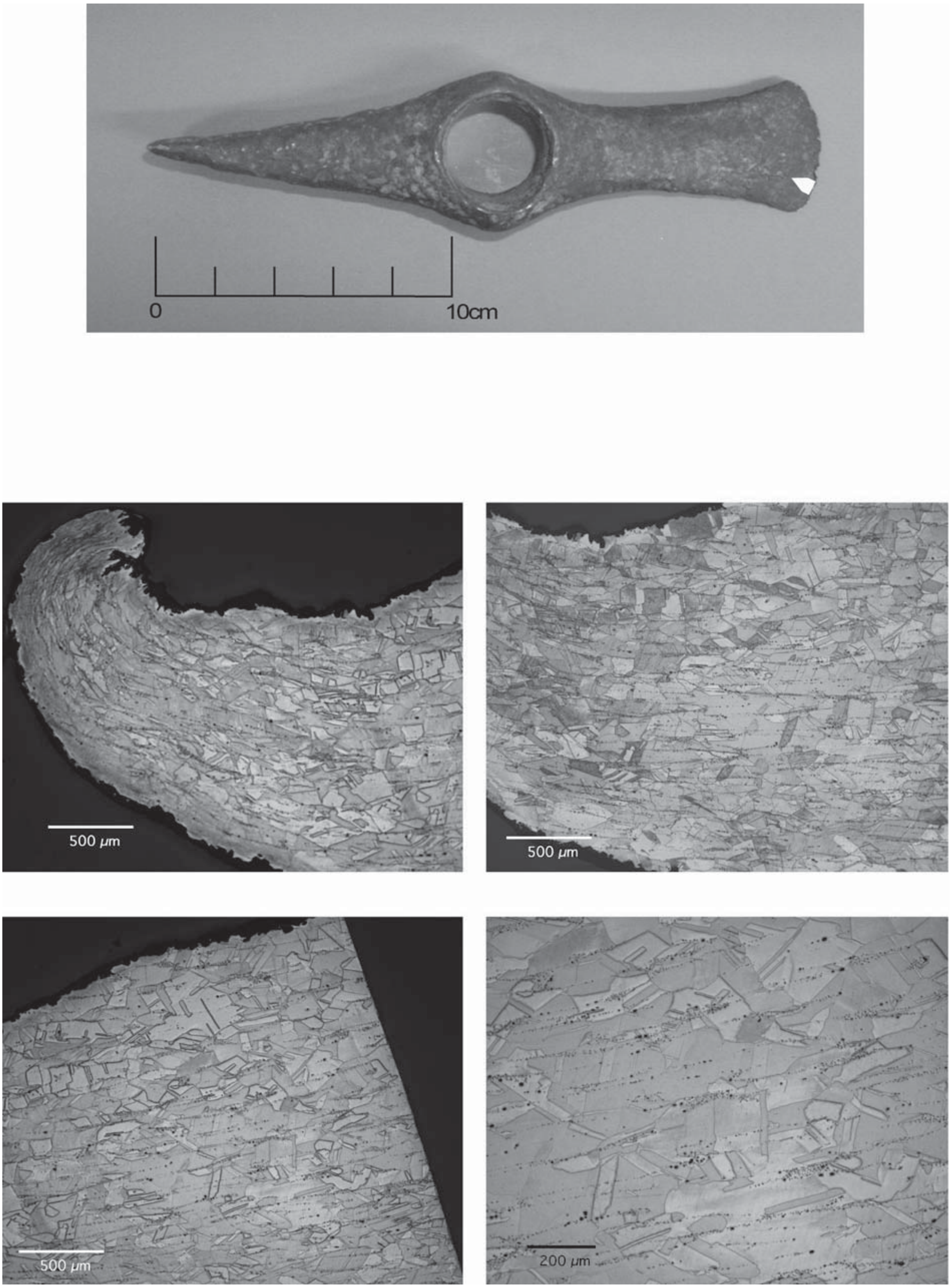
Tab. 21-1: Sample no. 105-1 (axe: 3:4).



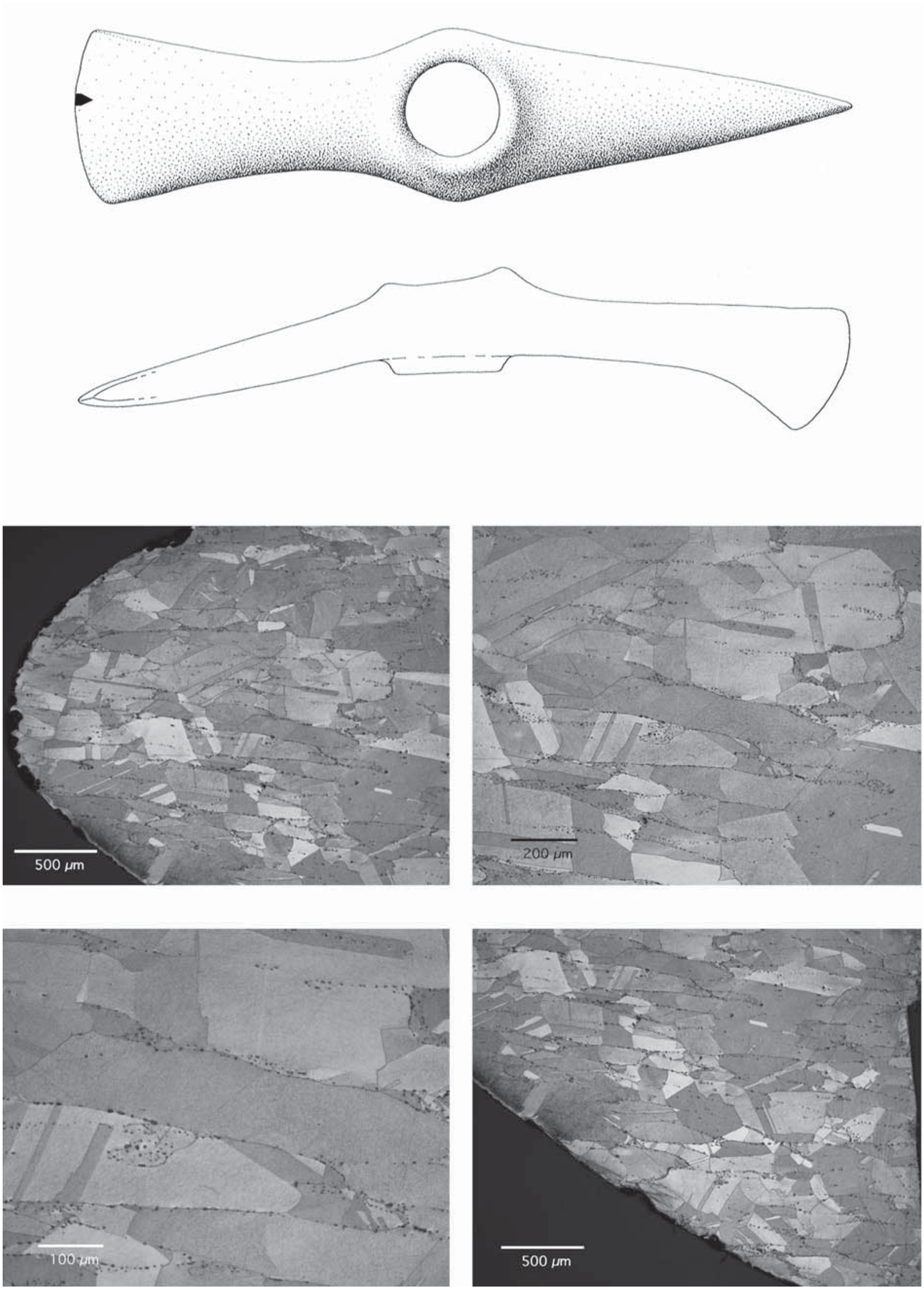
Tab. 21-2: Sample no. 105-2 (axe: 1:2).



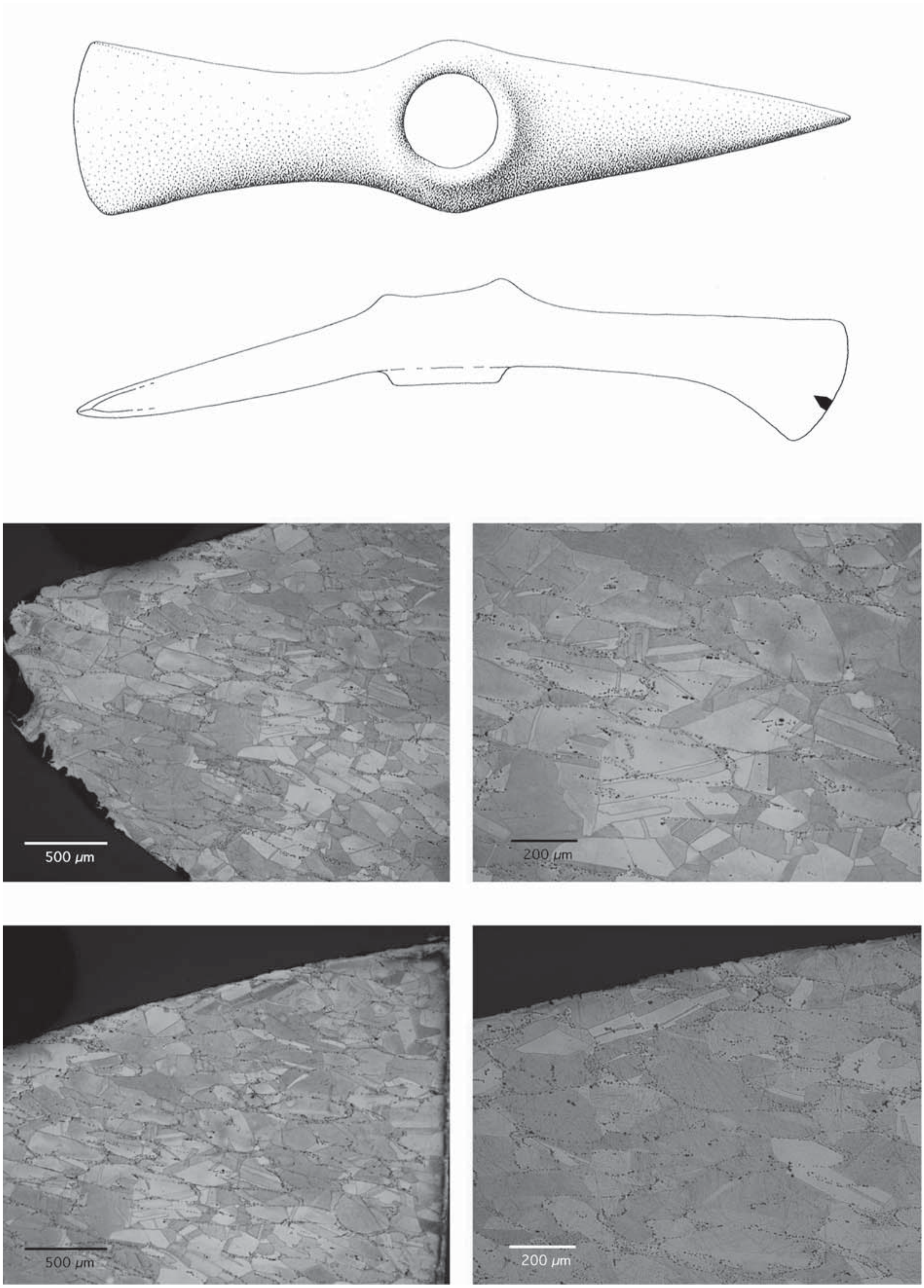
Tab. 22-1: Sample no. 107-1.



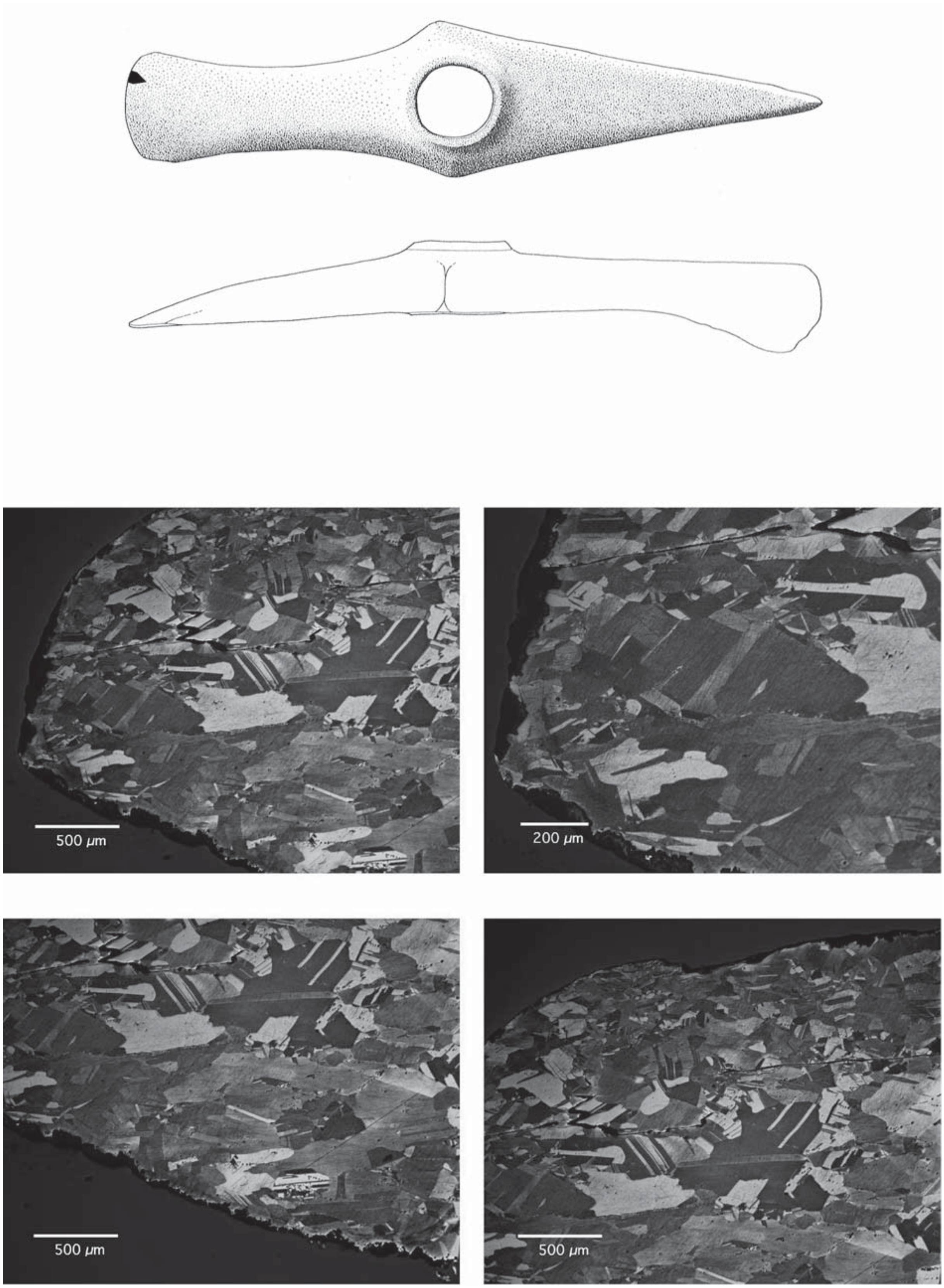
Tab. 22-2: Sample no. 107-2.



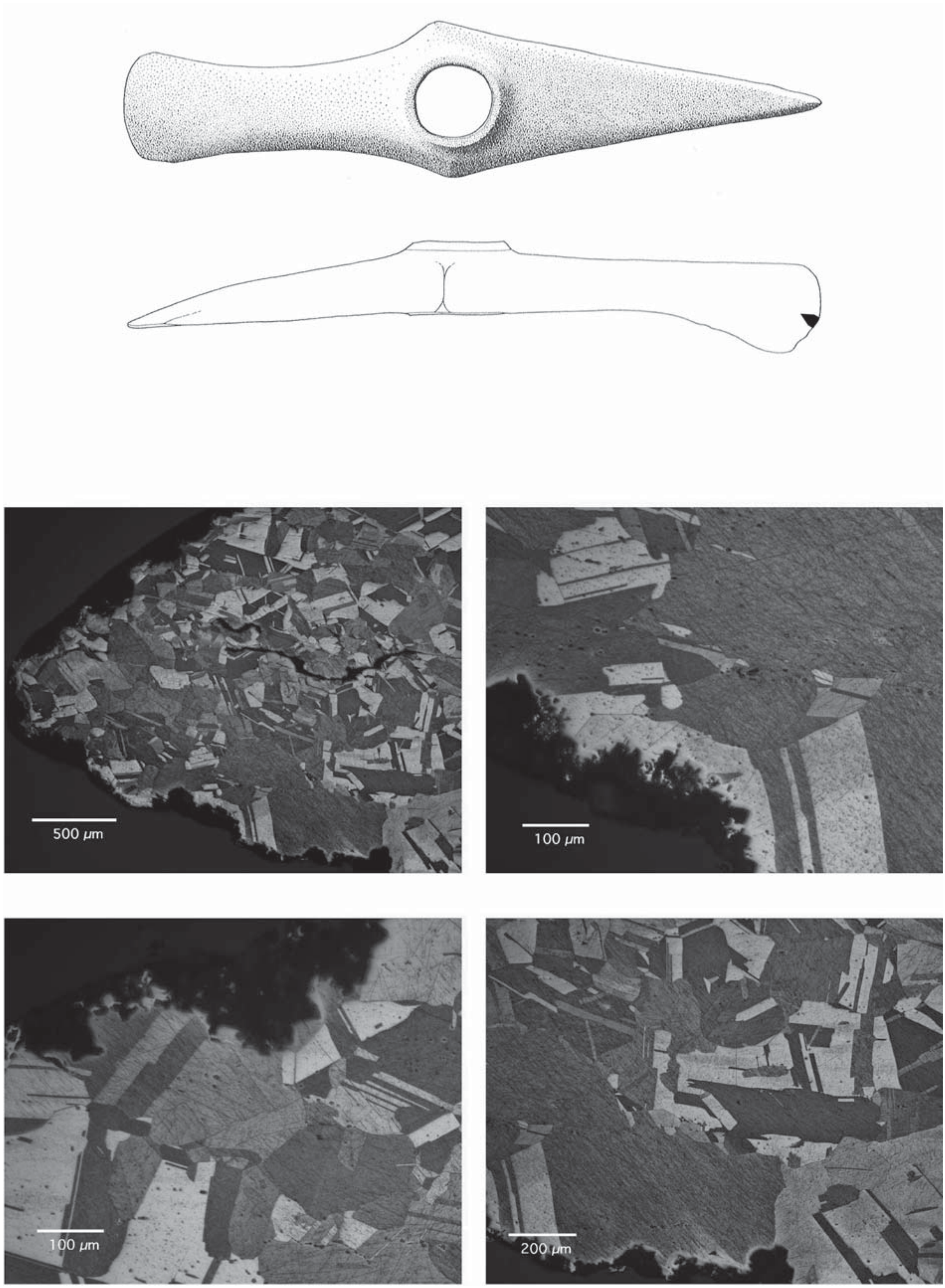
Tab. 23-1: Sample no. 138-1 (axe: 1:2).



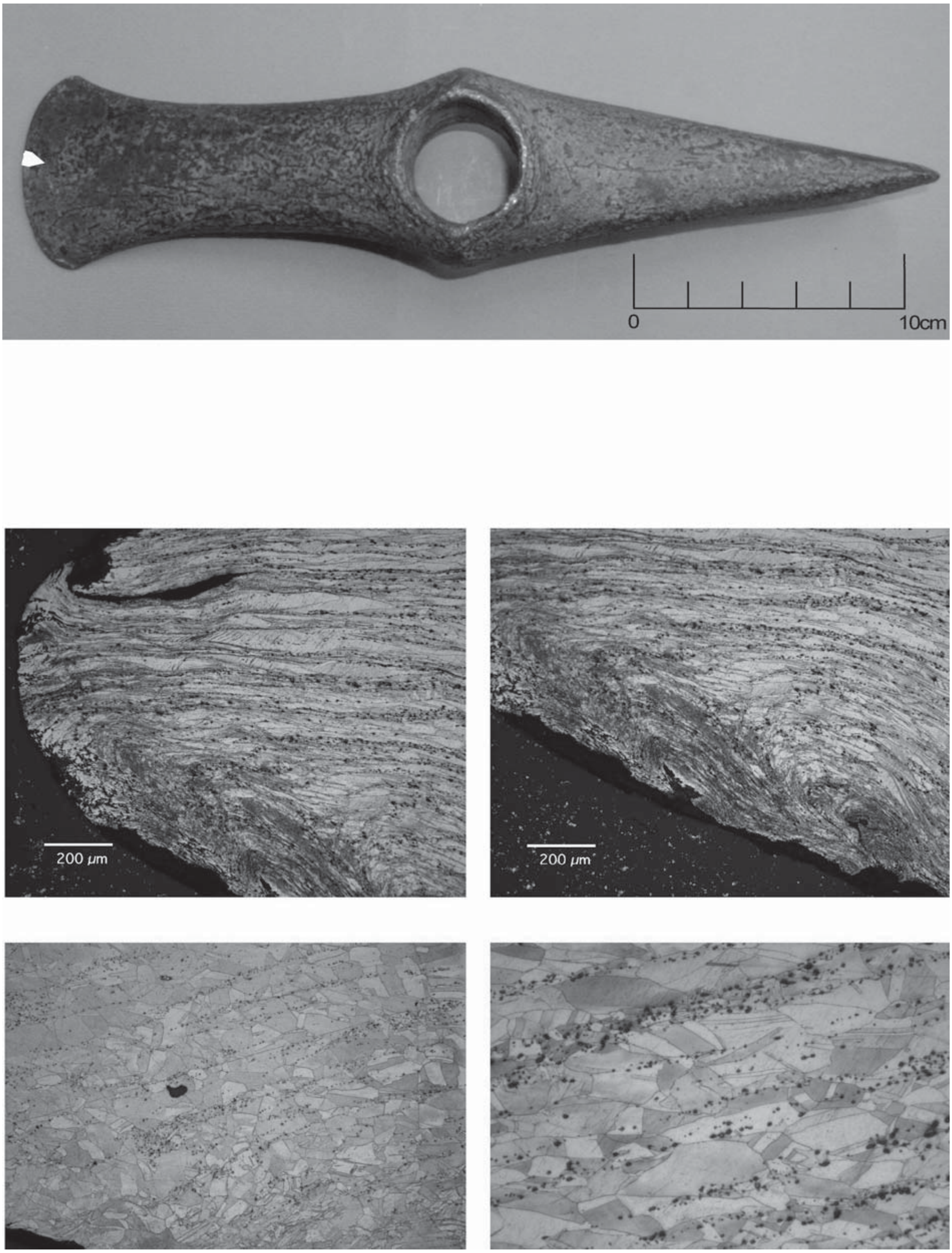
Tab. 23-2: Sample no. 138-2 (axe: 1:2).



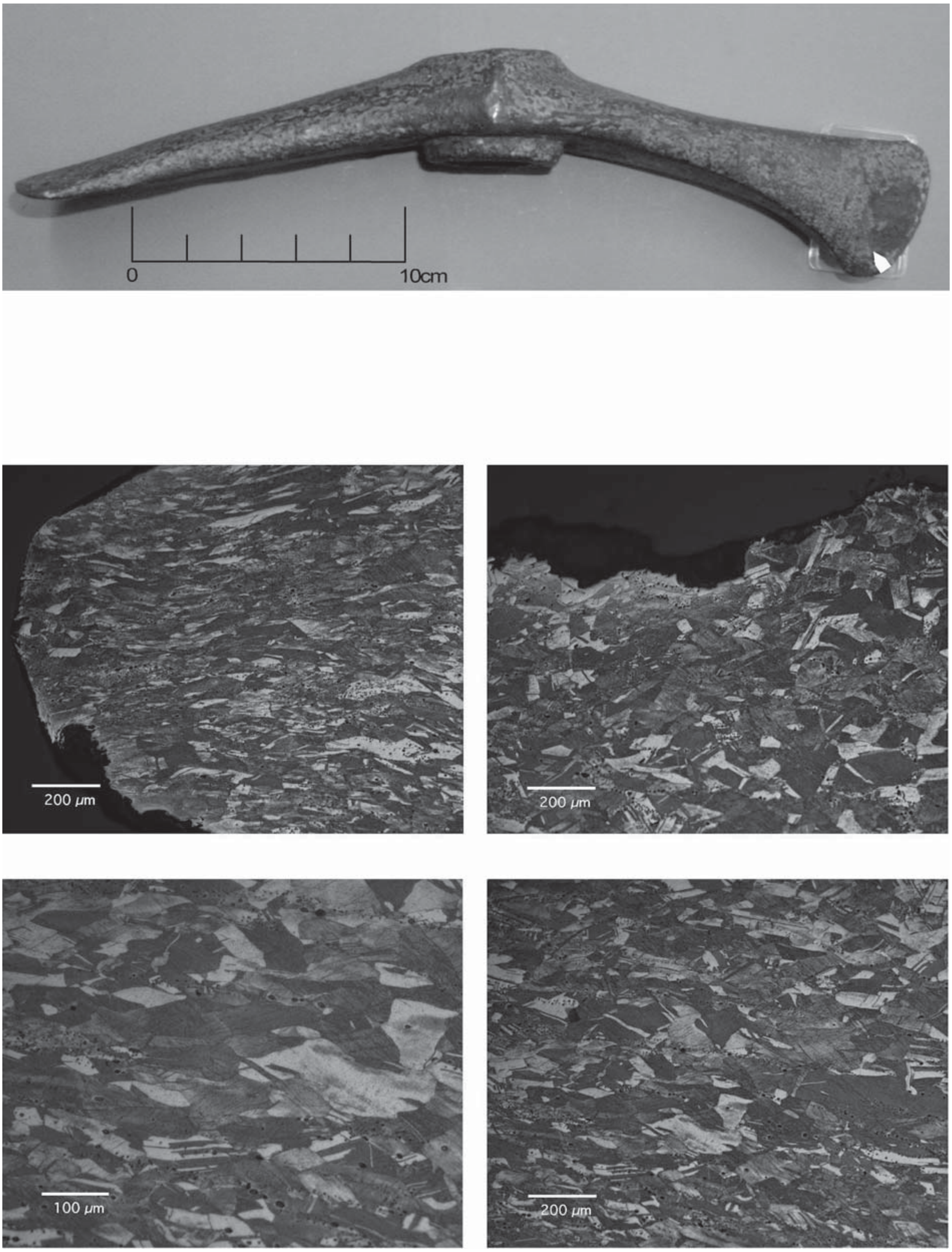
Tab. 24-1: Sample no. 175-1 (axe: 1:2).



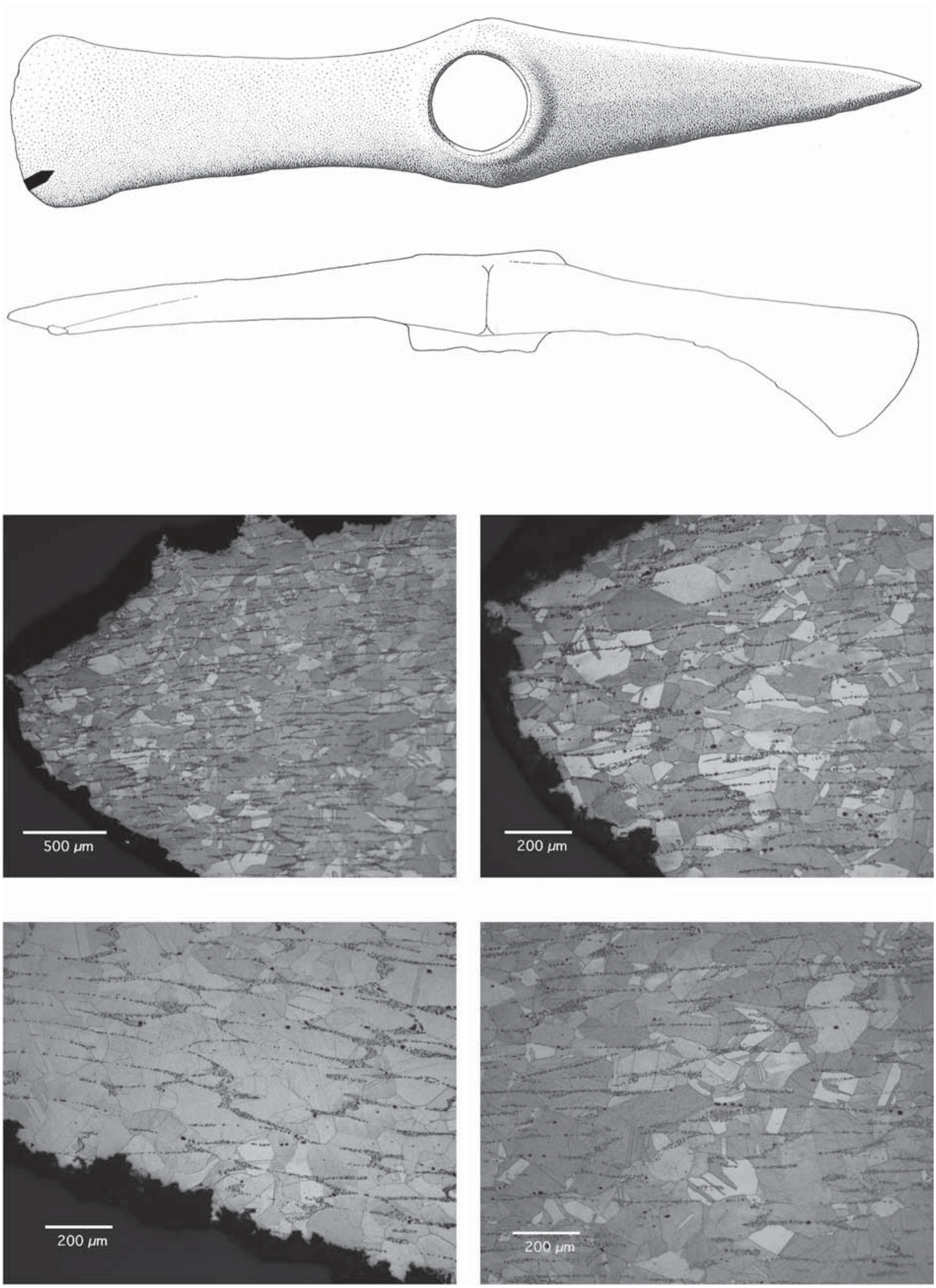
Tab. 24-2: Sample no. 175-2 (axe: 1:2).



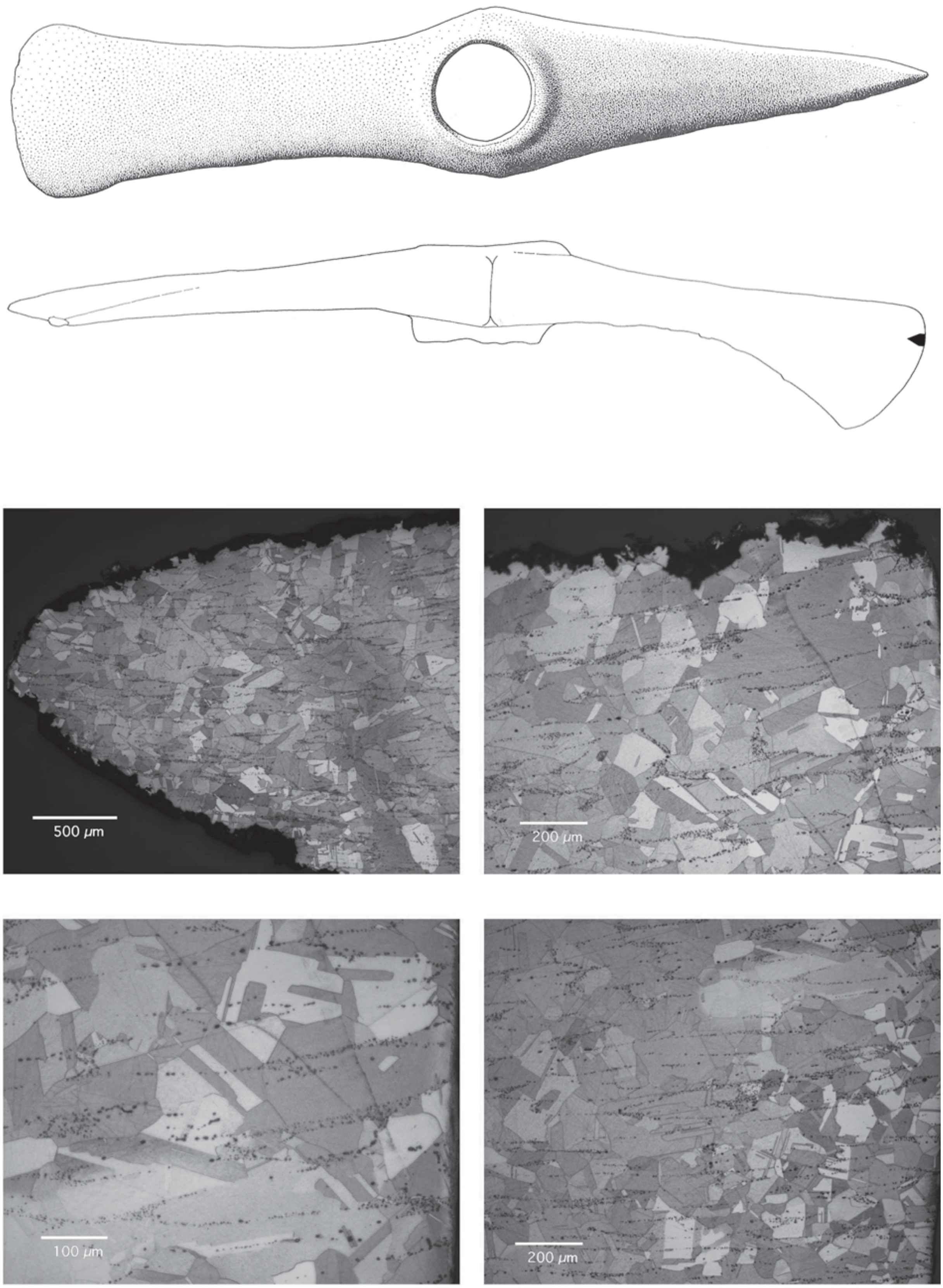
Tab. 25-1: Sample no. 177-1.



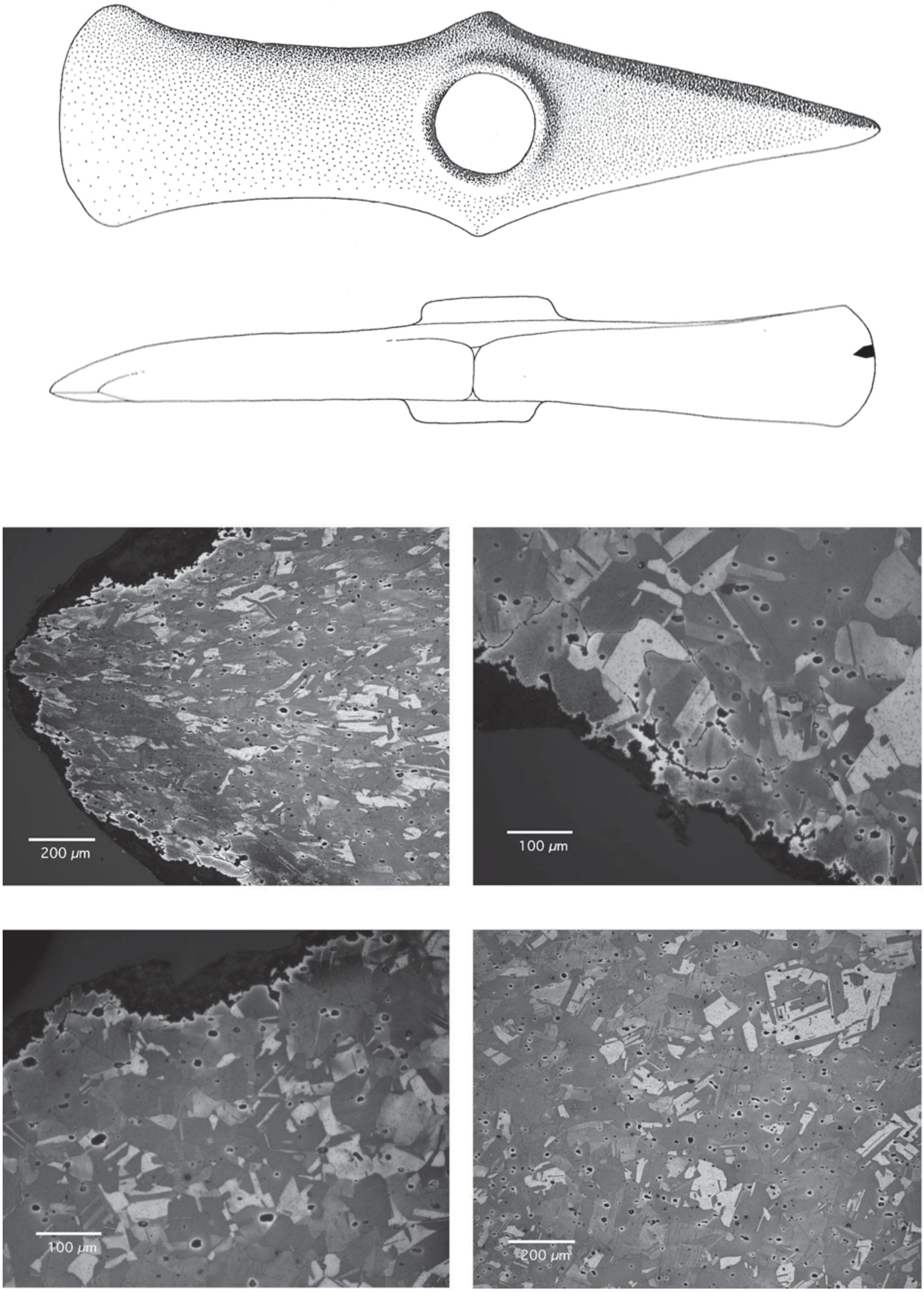
Tab. 25-2: Sample no. 177-2.



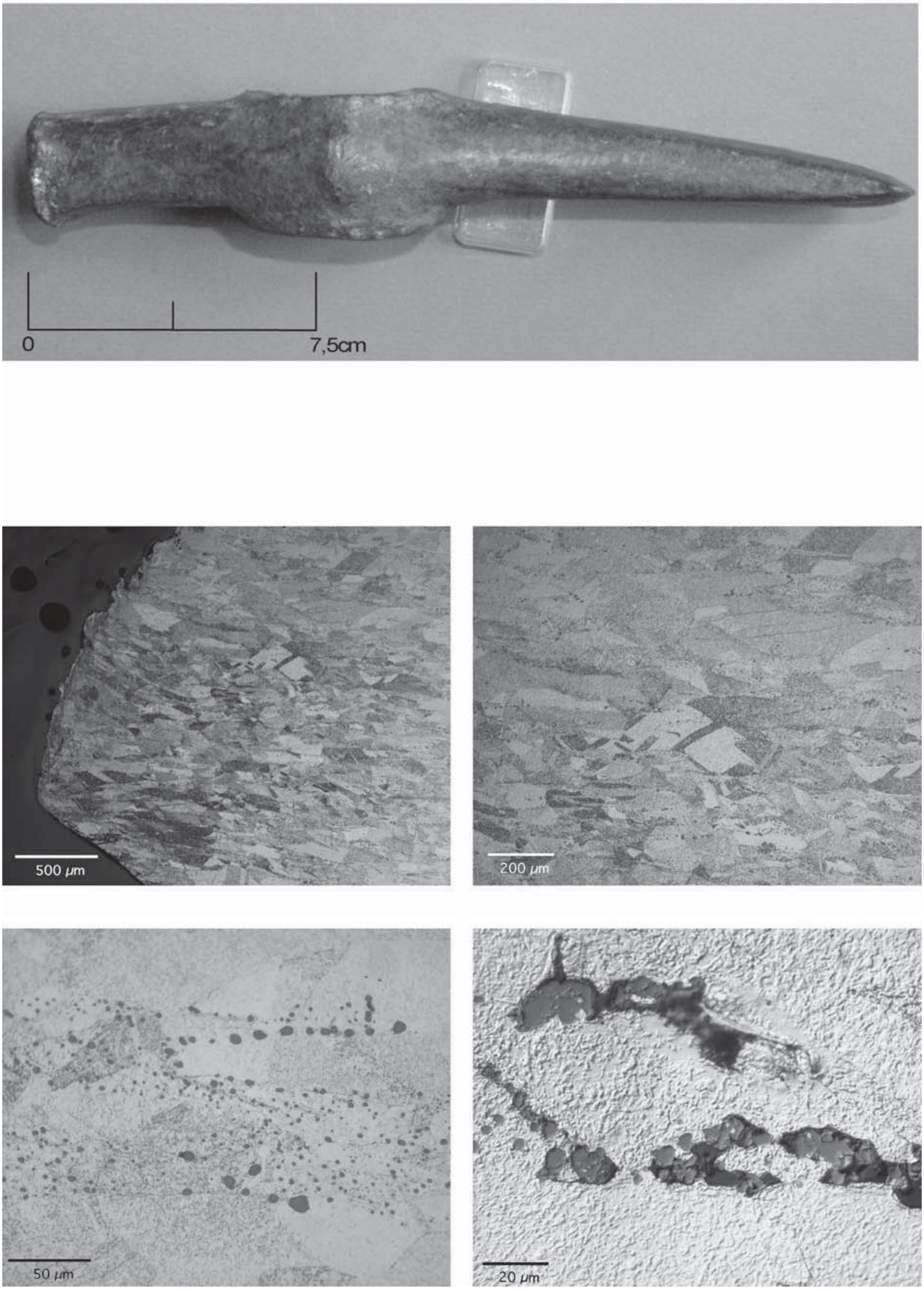
Tab. 26-1: Sample no. 178-1 (axe: 1:2).



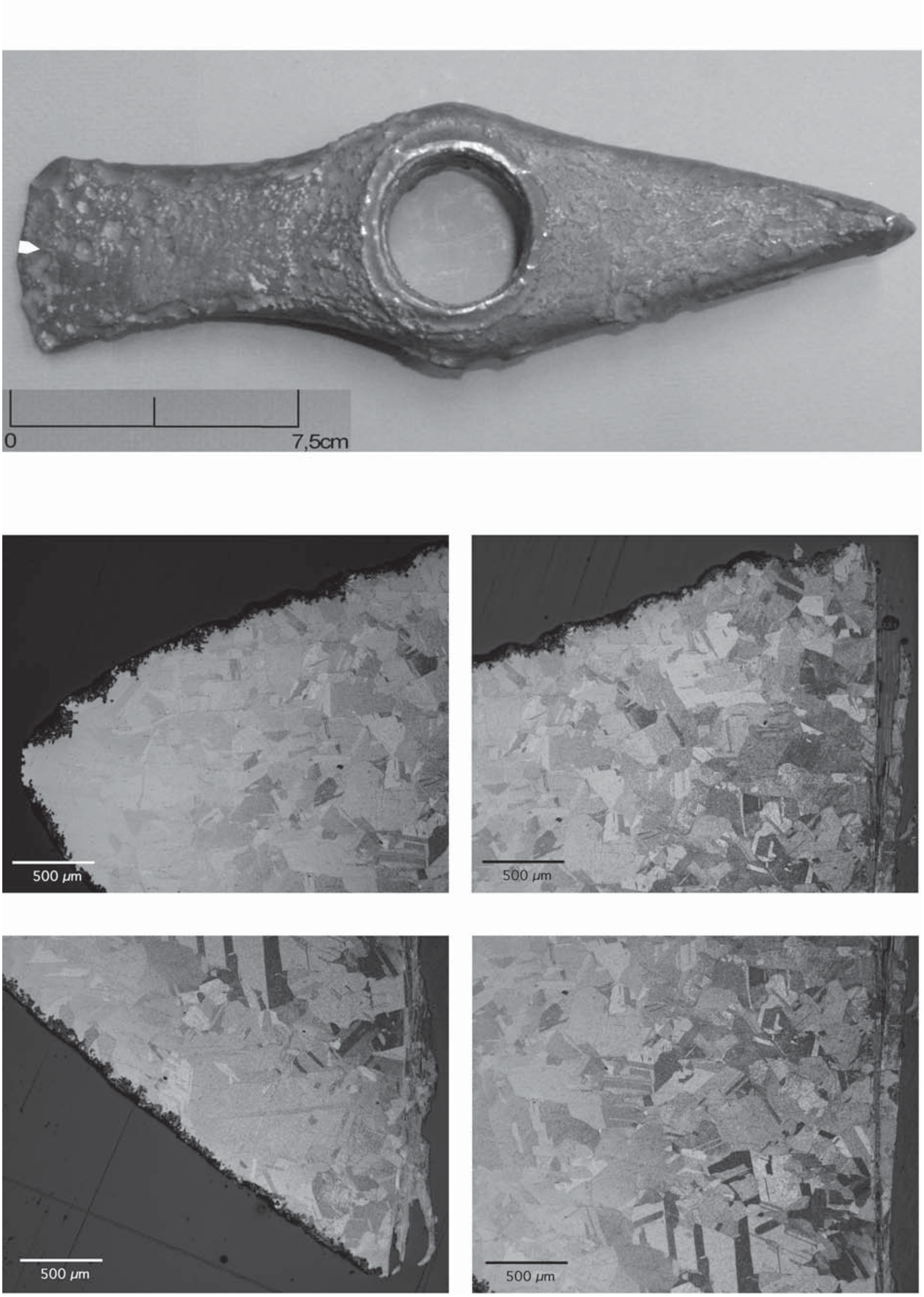
Tab. 26-2: Sample no. 178-2 (axe: 1:2).



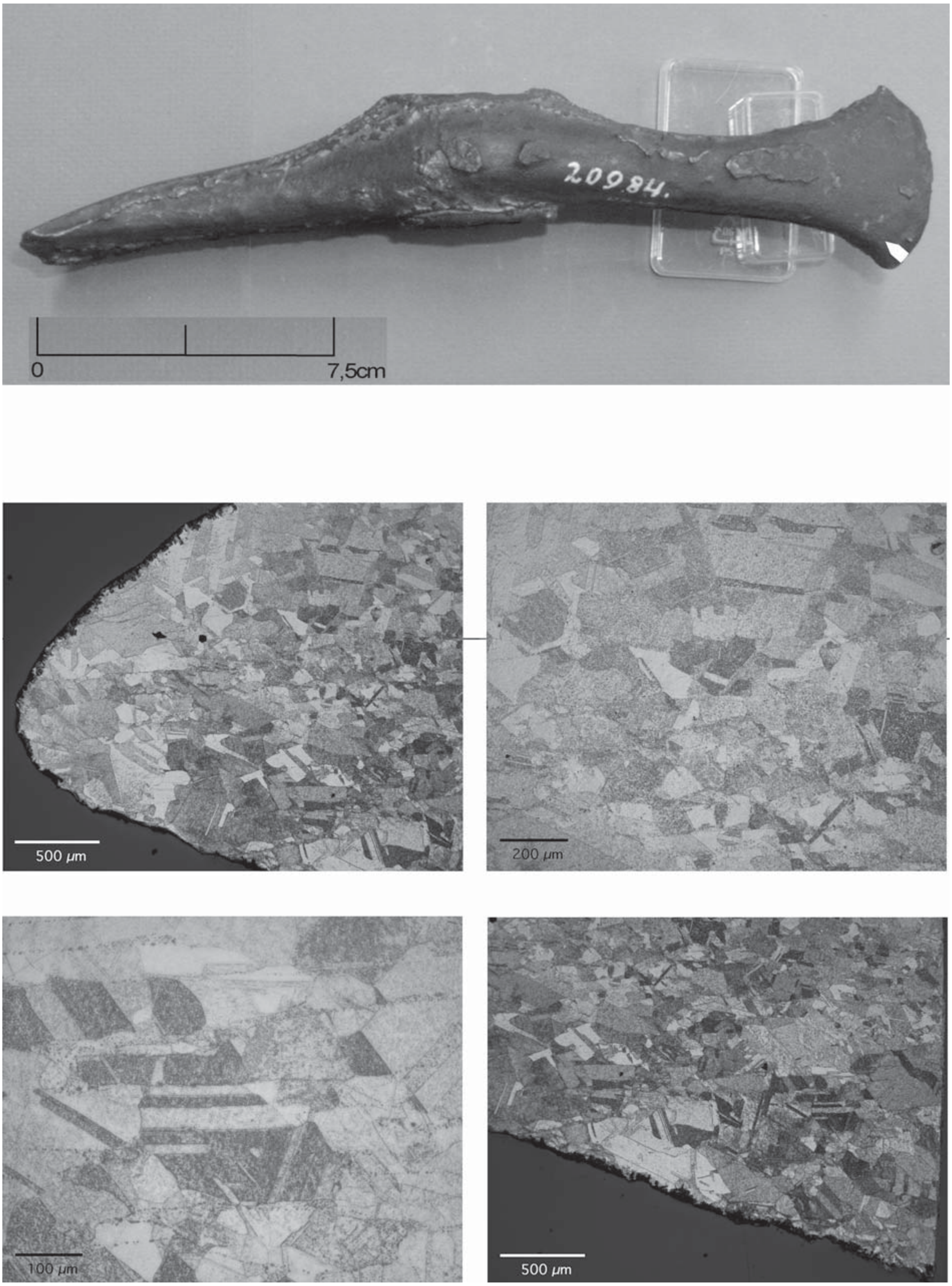
Tab. 27: Sample no. 179 (axe: 3:4).



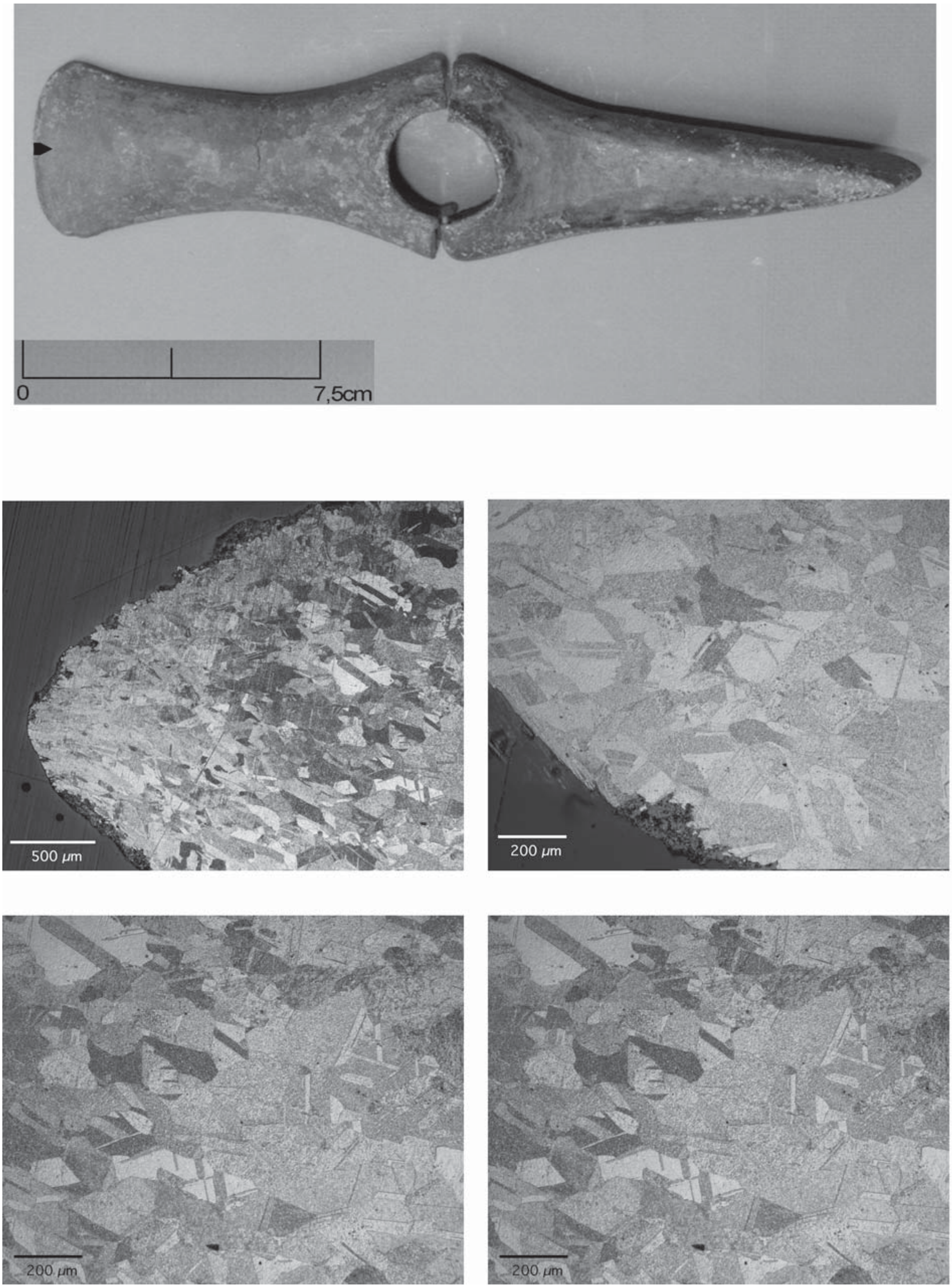
Tab. 28: Sample no. 189.



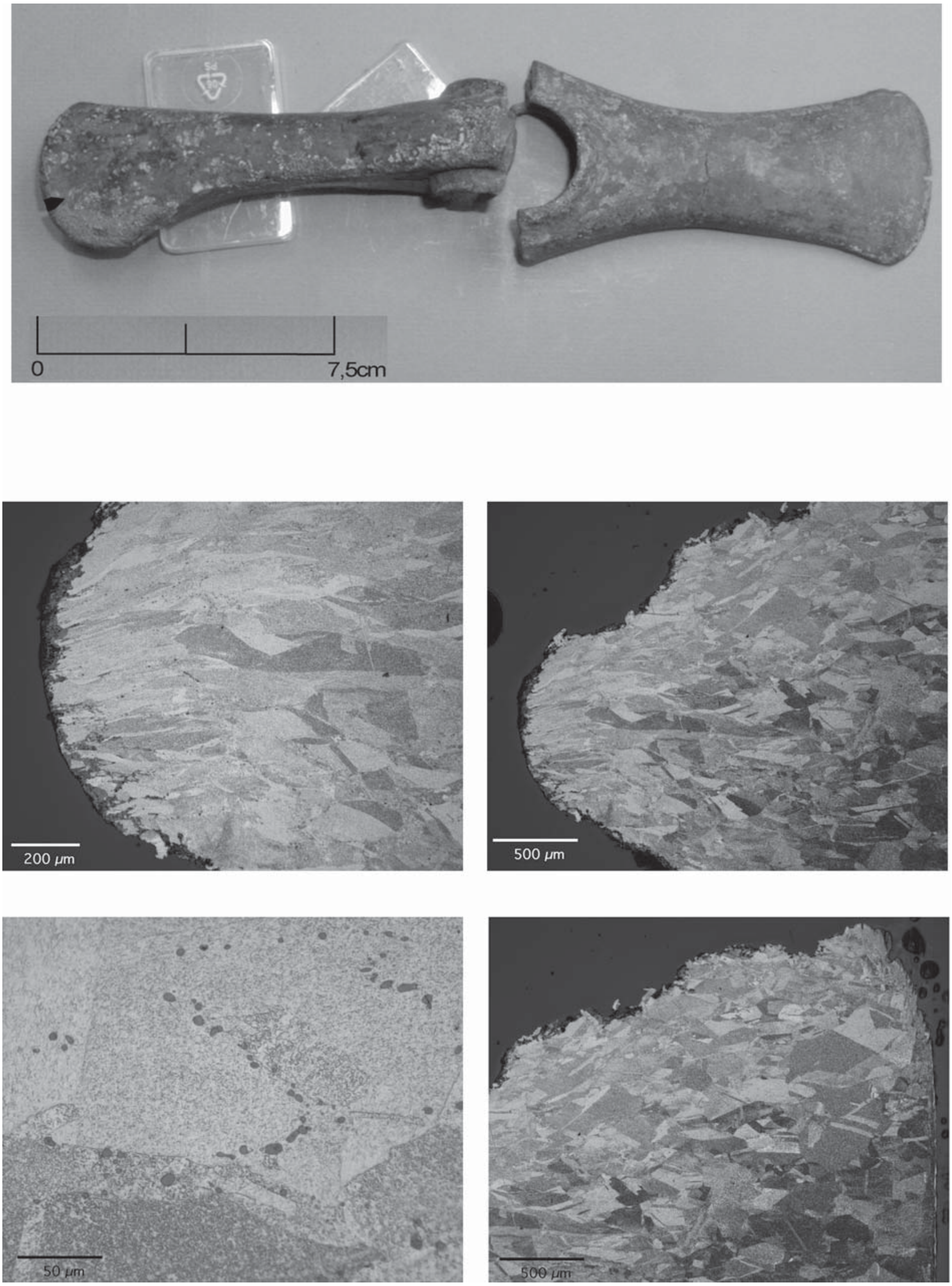
Tab. 29-1: Sample no. 205-1.



Tab. 29-2: Sample no. 205-2.

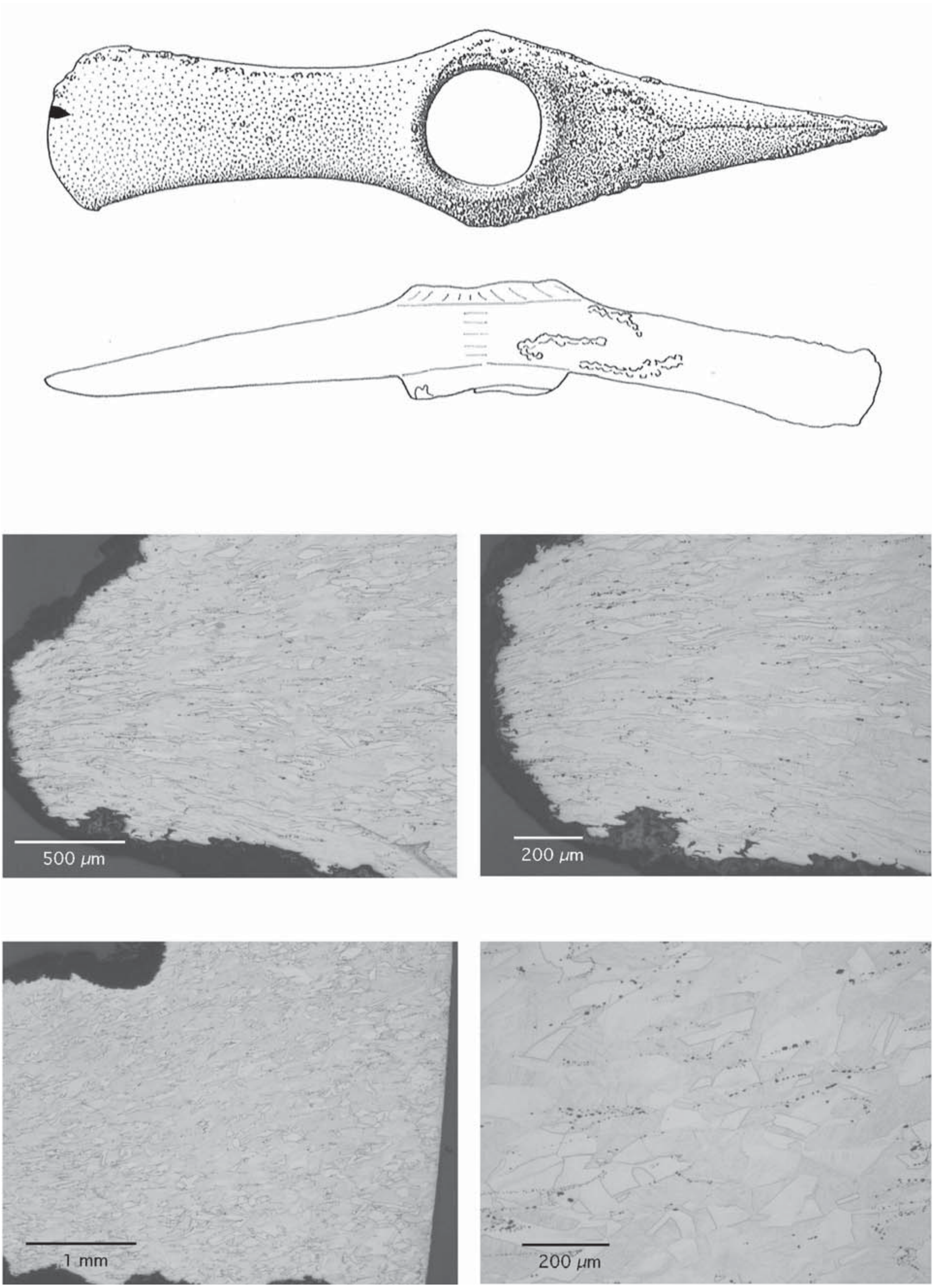


Tab. 30-1: Sample no. 206-1.

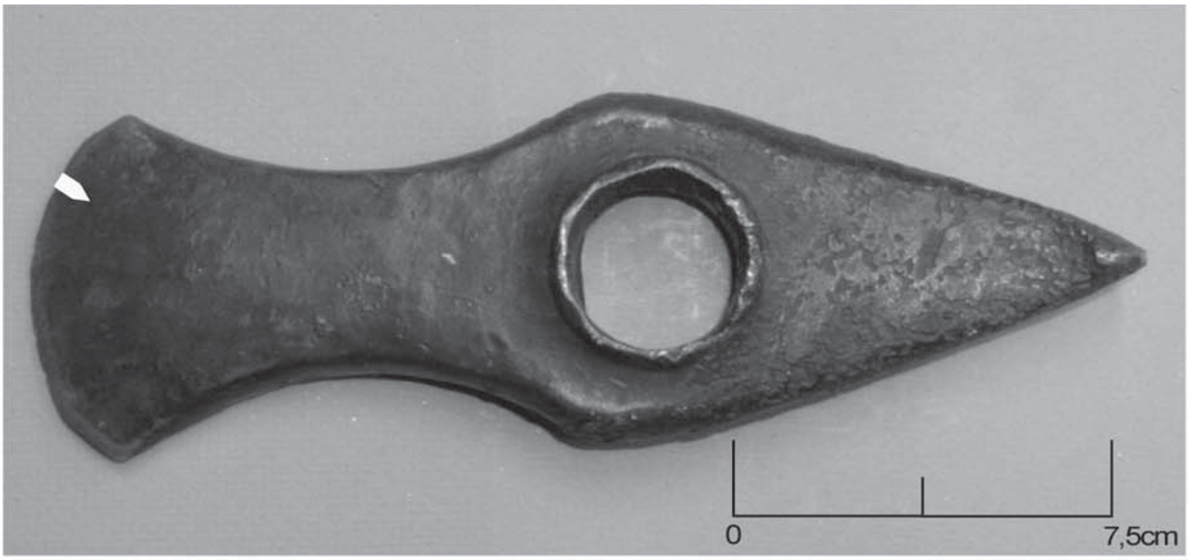


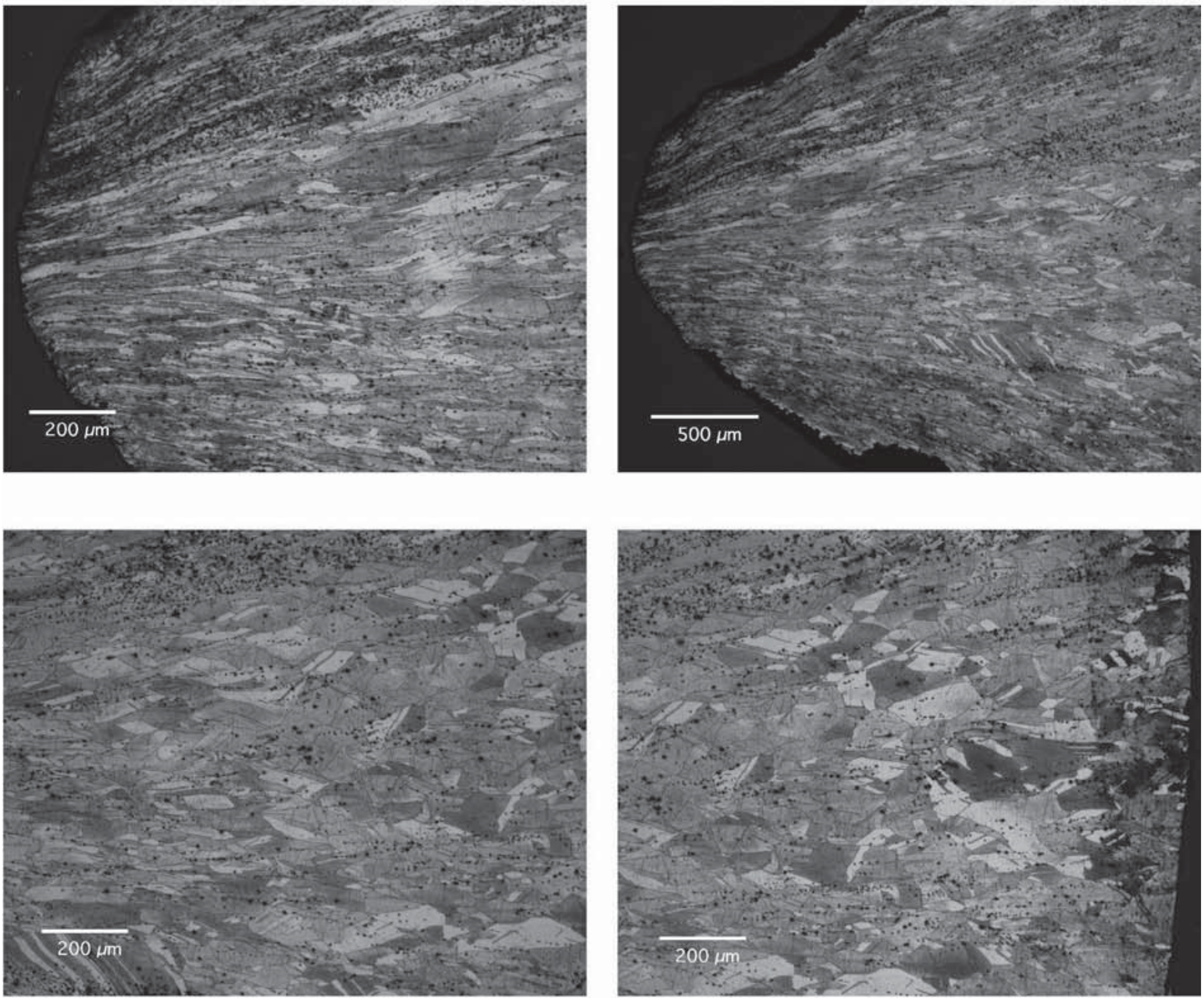
Tab. 30-2: Sample no. 206-2.

Eneolithic/Copper Age axe-adzes, type Kladari		
Sample no.	***Origin / context***	***Museum / inv. no.***
94	unknown unknown	Wien, Urgesch. Inst., 9102 Mayer 1977, 12 no. 31
180-1/-2	Tijesno Vrbasa / Bočac BiH unknown	Wien, NHM, 38925 Žeravica 1993, 18 no. 35

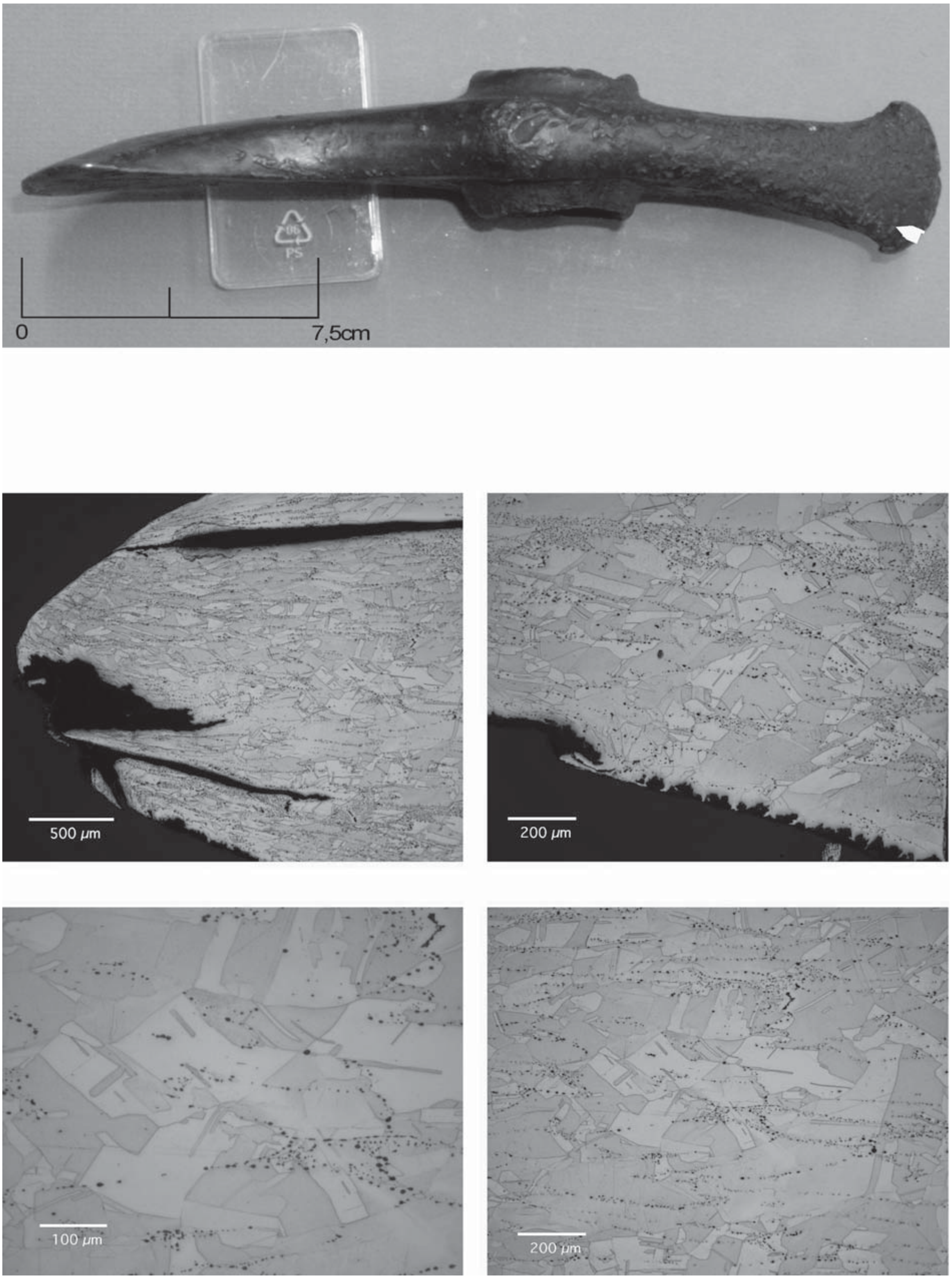


Tab. 31: Sample no. 94 (axe: 3:4).



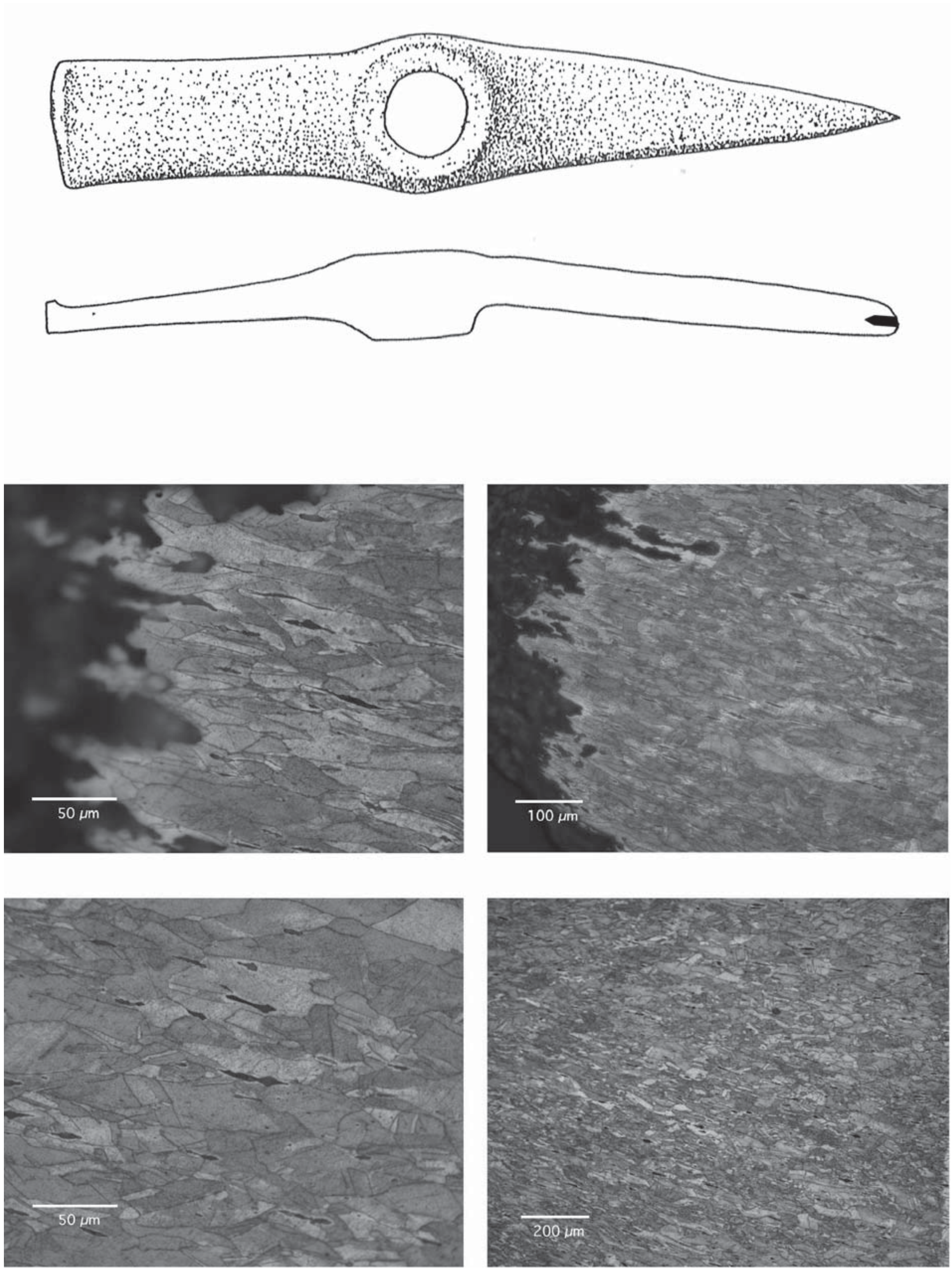


Tab. 32-1: Sample no. 180-1.

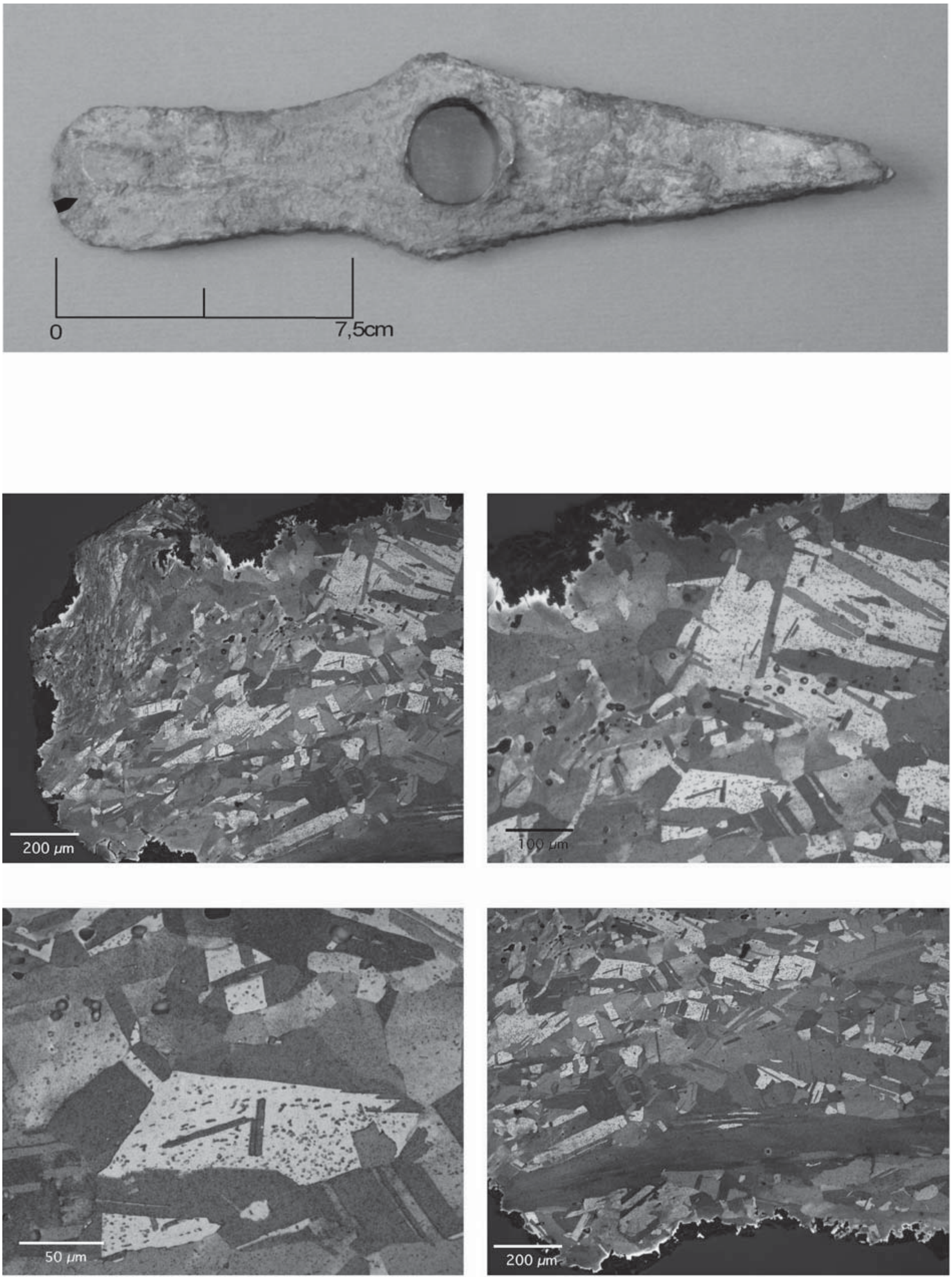


Tab. 32-2: Sample no. 180-2.

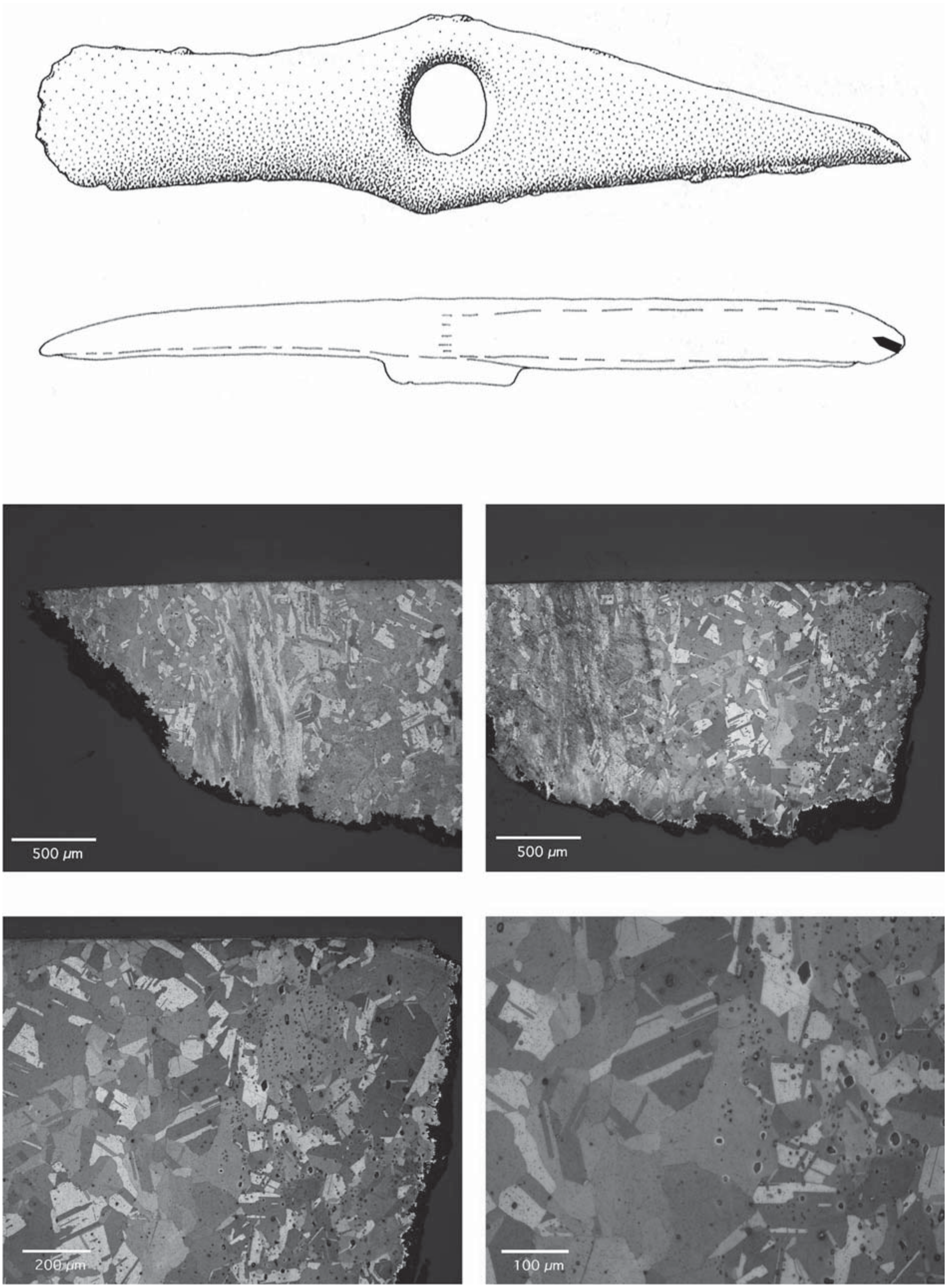
Eneolithic/Copper Age axe-adzes, type Nógrádmarcal		
Sample no.	***Origin / context***	***Museum / inv. no.***
52	Malé Leváre SK hoard (see sample no. 55)	Bratislava, Slov. Nár. Múz. Novotná 1970, 25–26 no. 125
118-1/-2	Skrbeň CZ stray find	Olomouc, A 52022/P81-70 Říhovský 1992, 31 no. 16 (Gr. Ic, Typ Ib, Var. D/E)



Tab. 33: Sample no. 52 (axe: 3:4).

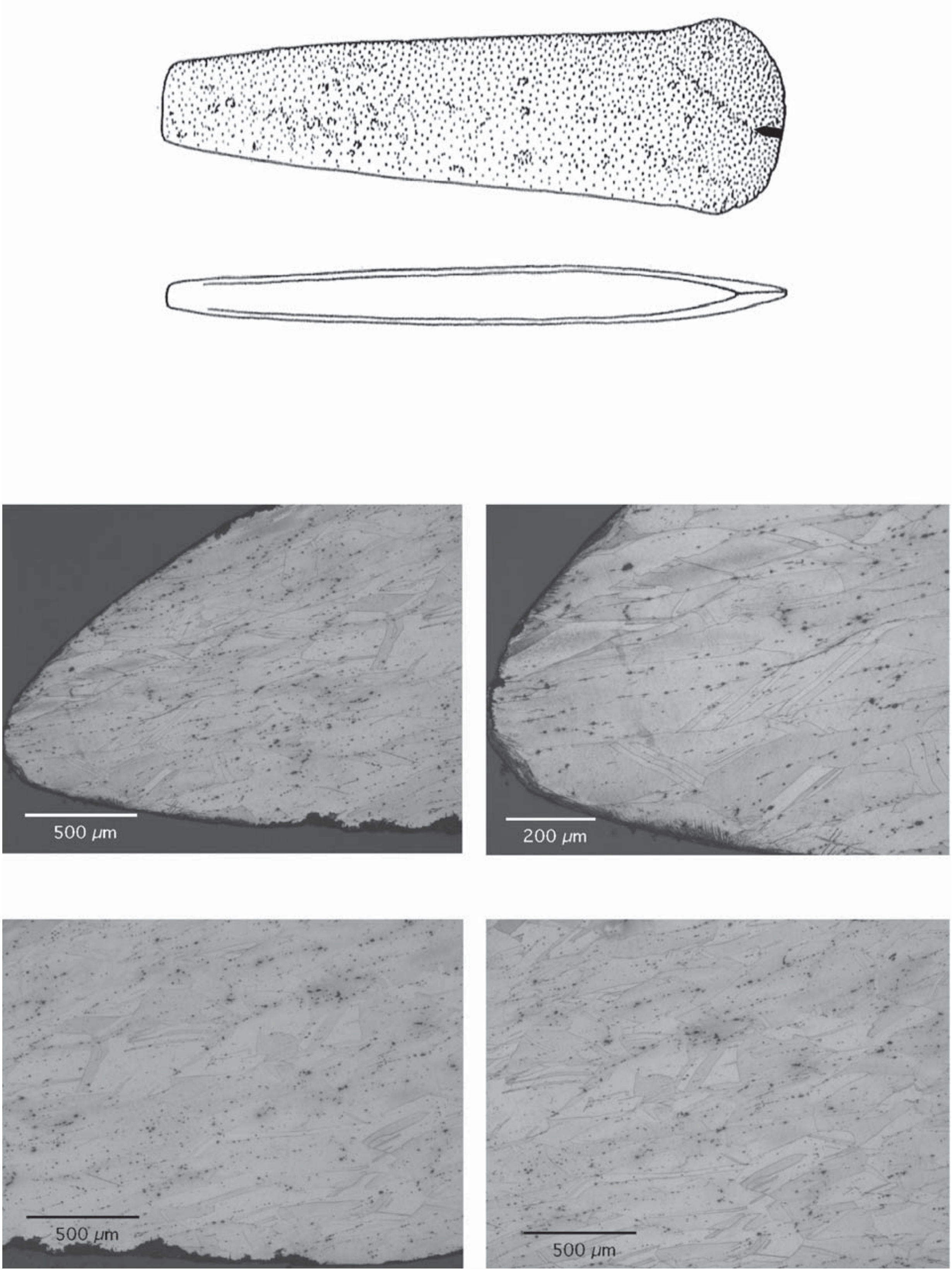


Tab. 34-1: Sample no. 118-1.

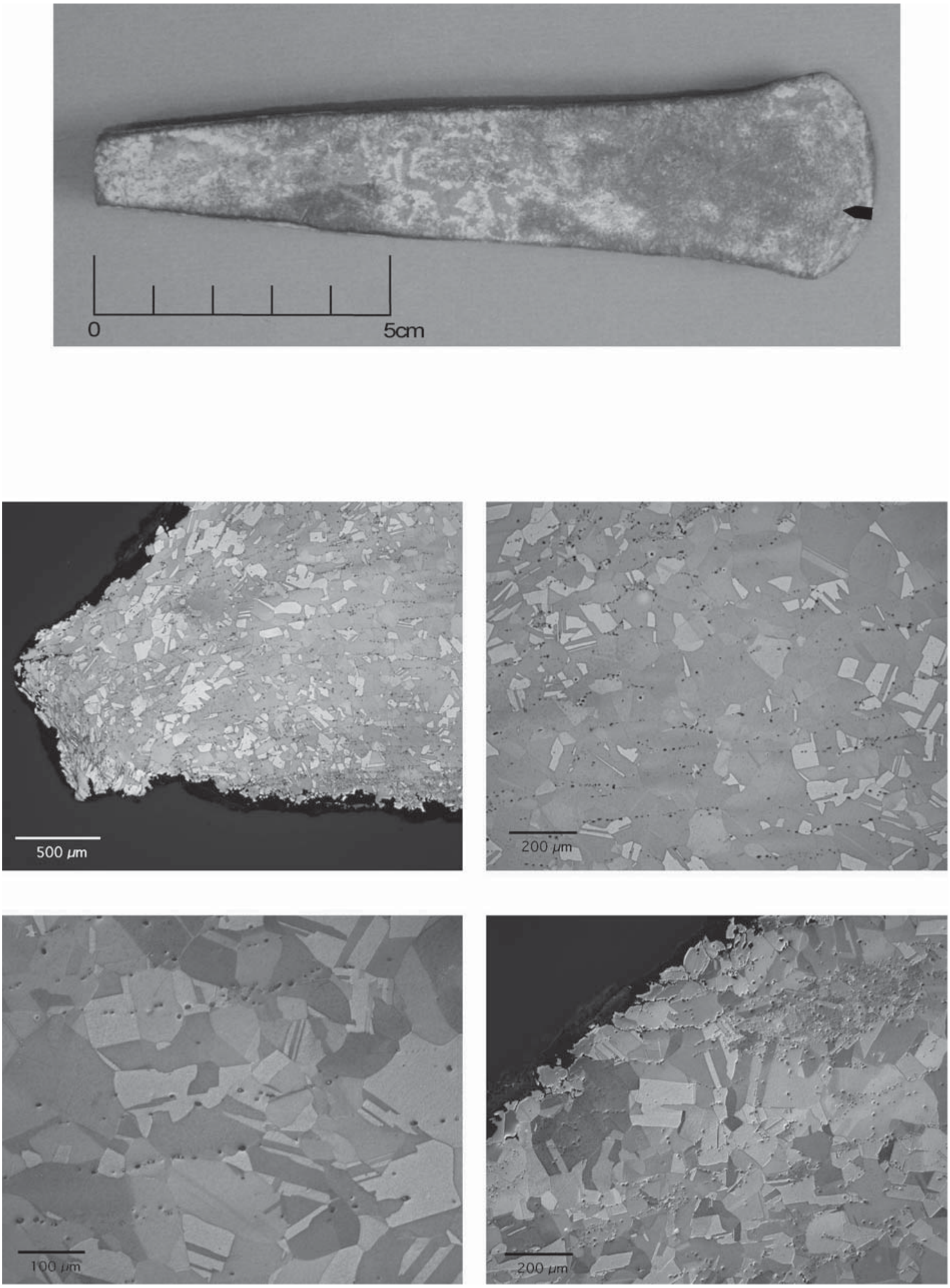


Tab. 34-2: Sample no. 118-2 (axe: 3:4).

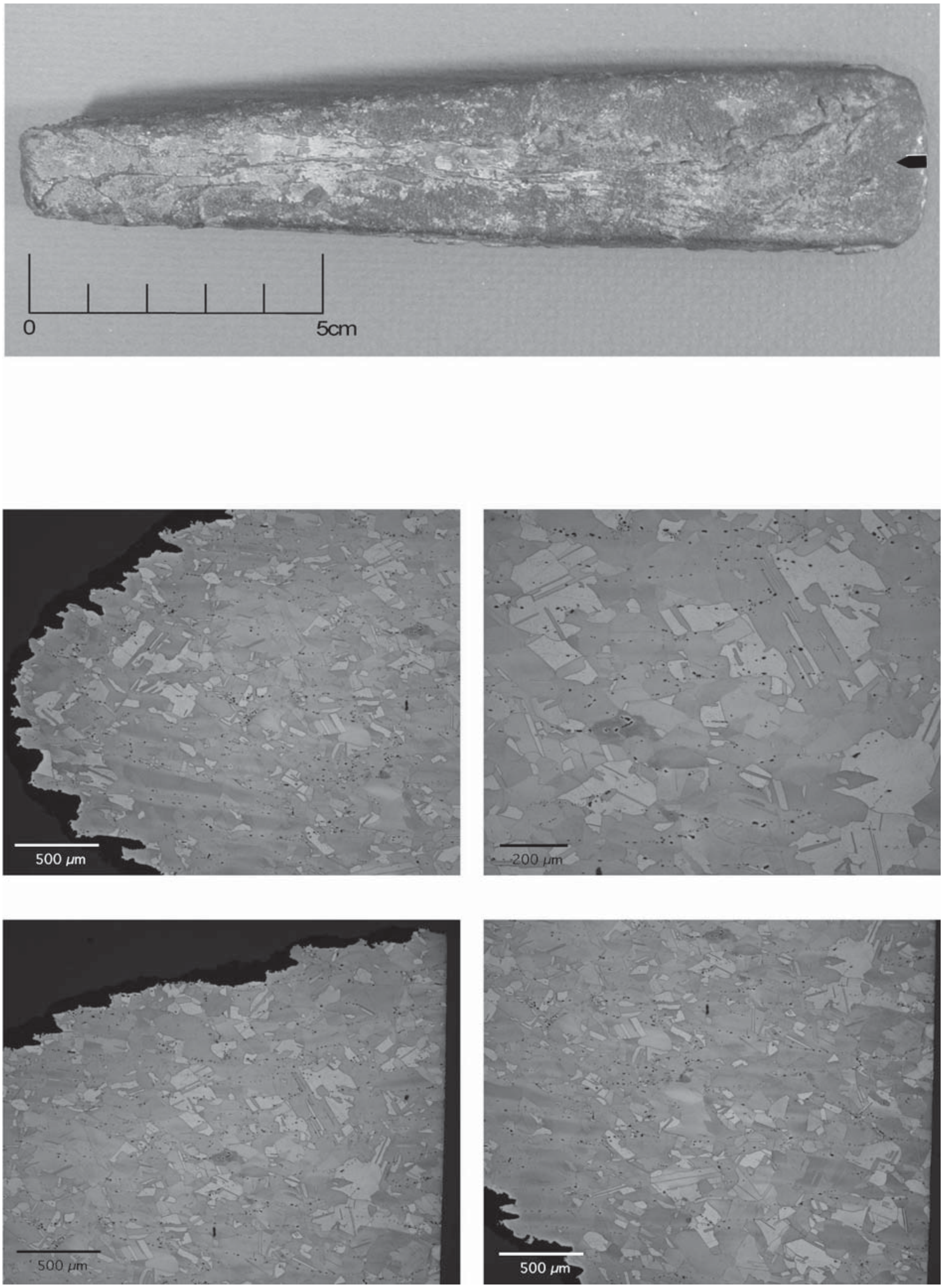
Eneolithic/Copper Age flat axes, horizon 1 (group 1: Stollhof etc.)		
Sample no.	***Origin / context***	***Museum / inv. no.***
84	unknown unknown	Wien, Urgesch. Inst., 9028 Mayer 1977, 52 no. 129 (kleine Flachbeile)
123	Litovel CZ stray find	Olomouc, A 62469 – P90/76 Říhovský 1992, 58 no. 66 (Gr. I, Typ 2b, Var. Bb)
137	Kobeřice CZ stray find	Brno, 1119/38 Říhovský 1992, 57 no. 61 (Gr. I, Typ 2a, Var. Bb)
140	Košátky CZ unknown	Brno, 69510
156	Ostrožská Lhota CZ stray find	Brno, 69508 Říhovský 1992, 60 no. 76 (Gr. III, Typ 2a, Var. Bb)



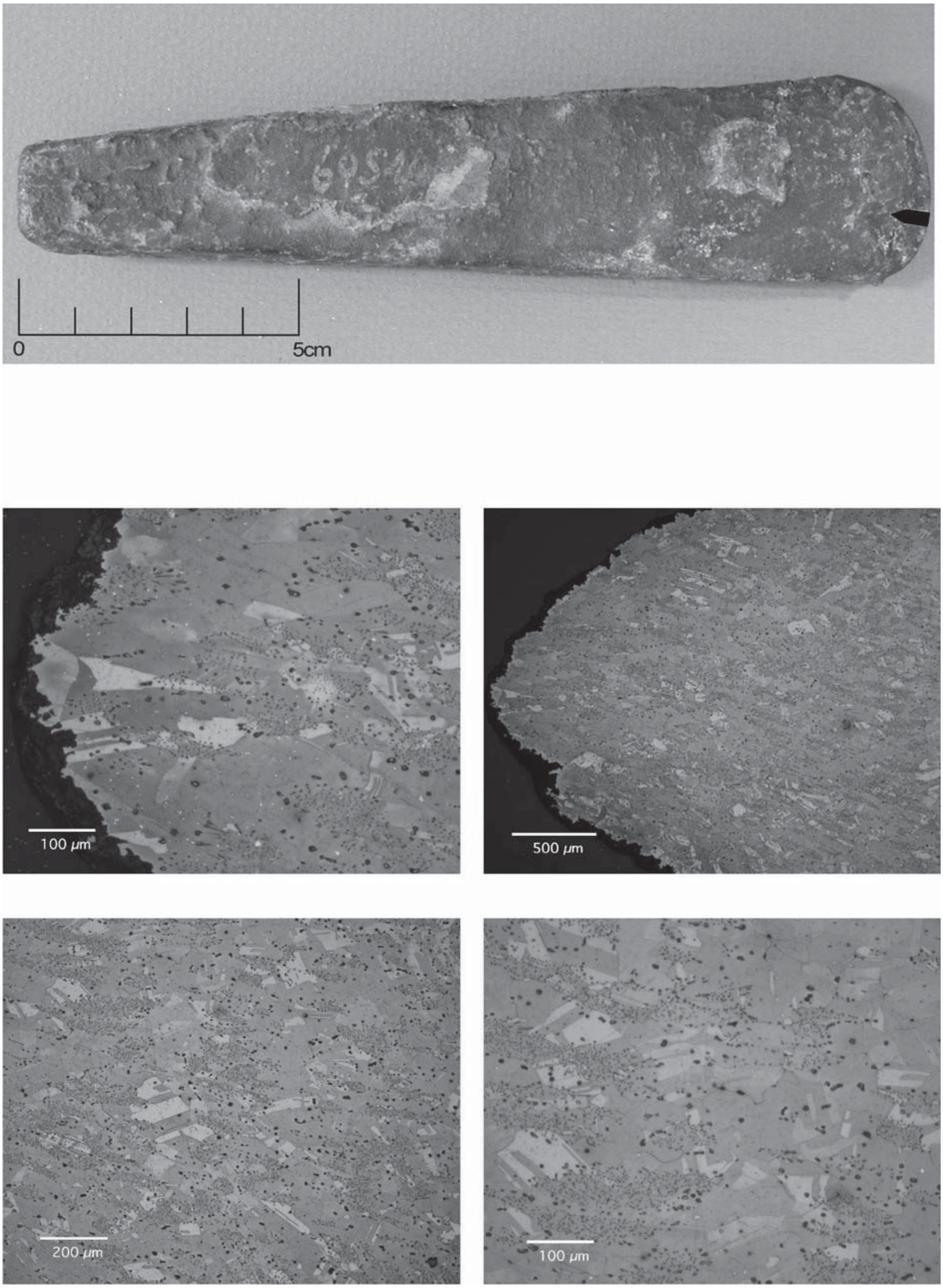
Tab. 35: Sample no. 84 (axe: 1:1).



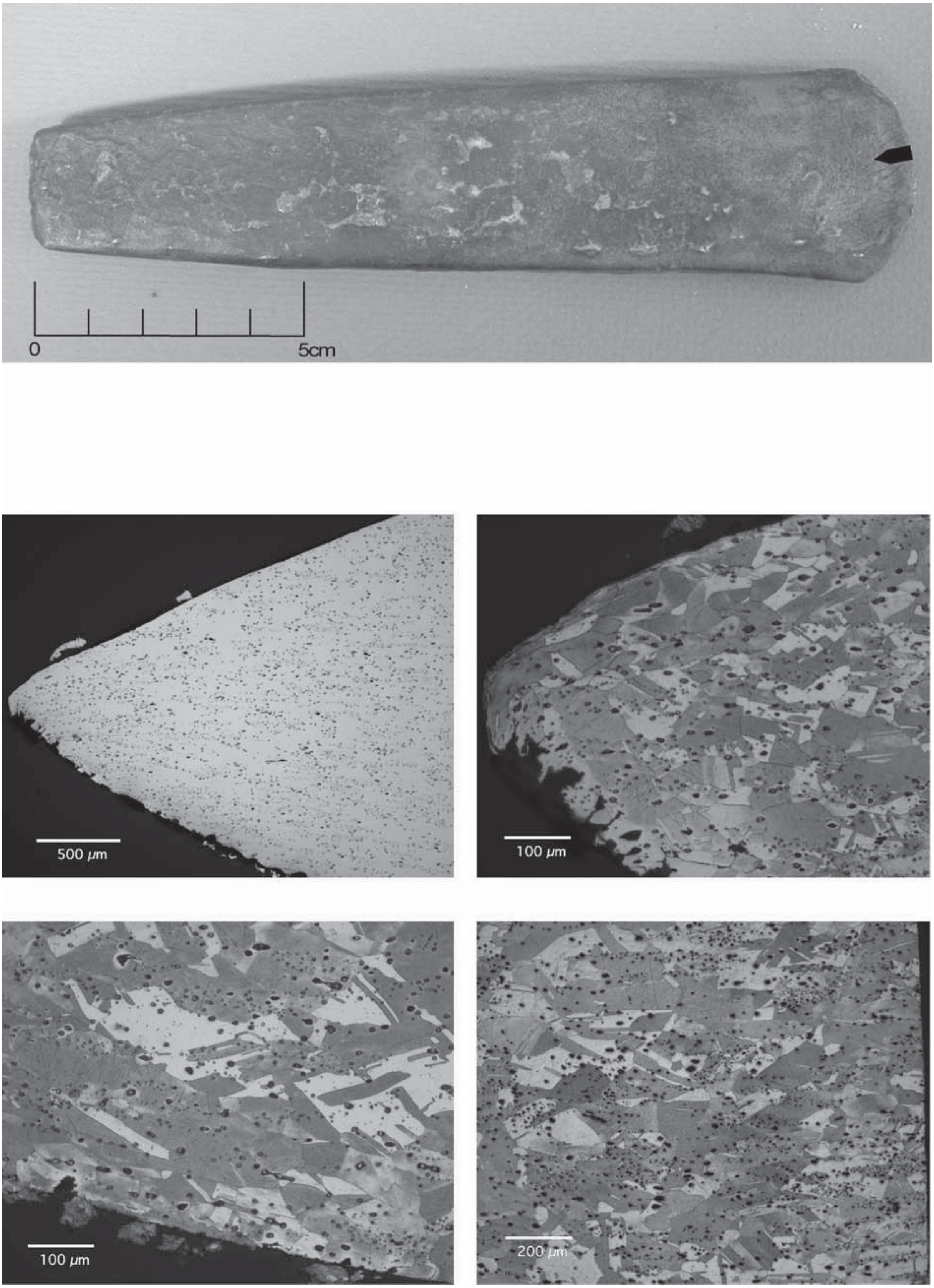
Tab. 36: Sample no. 123.



Tab. 37: Sample no. 137.

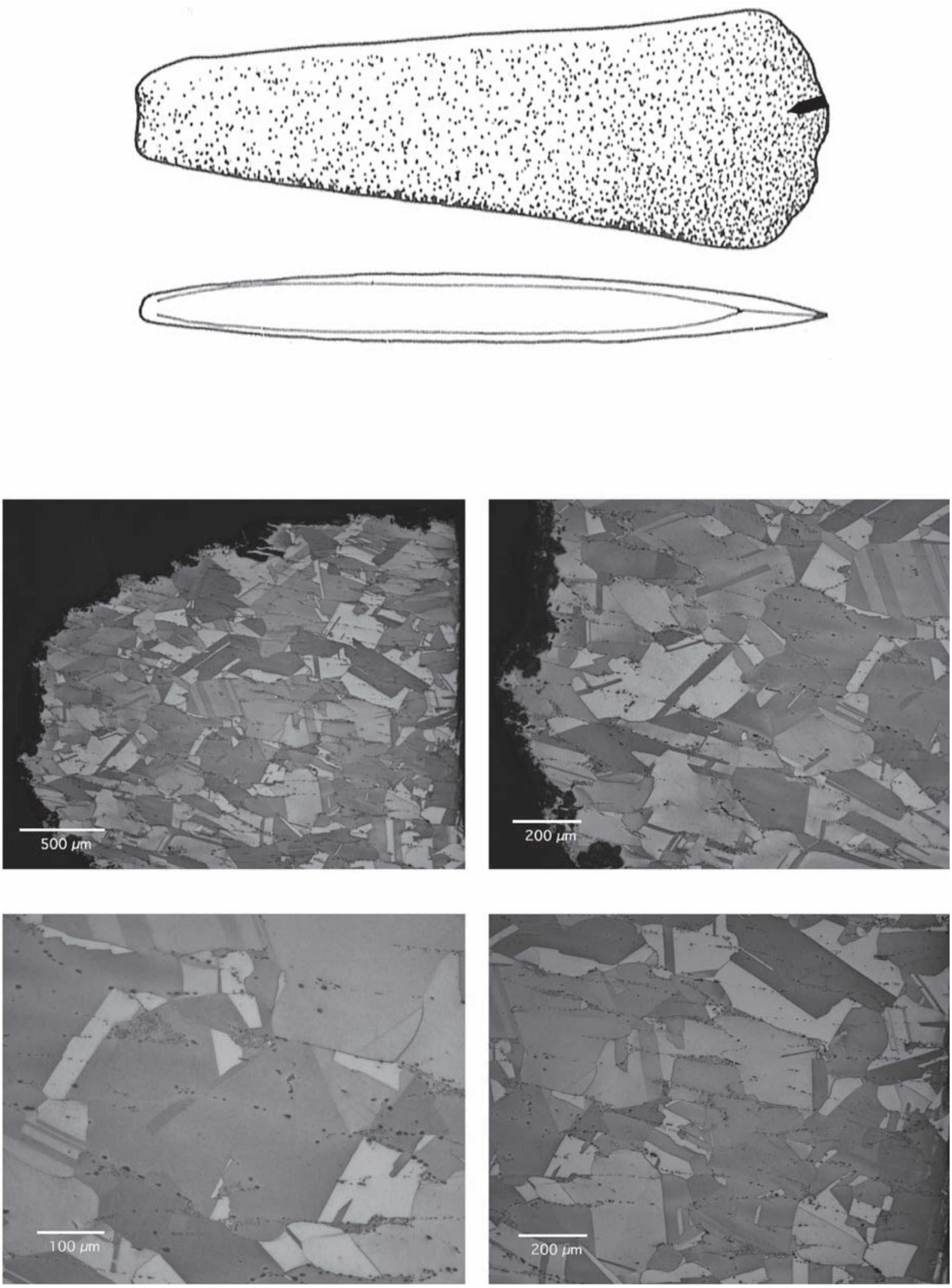


Tab. 38: Sample no. 140.

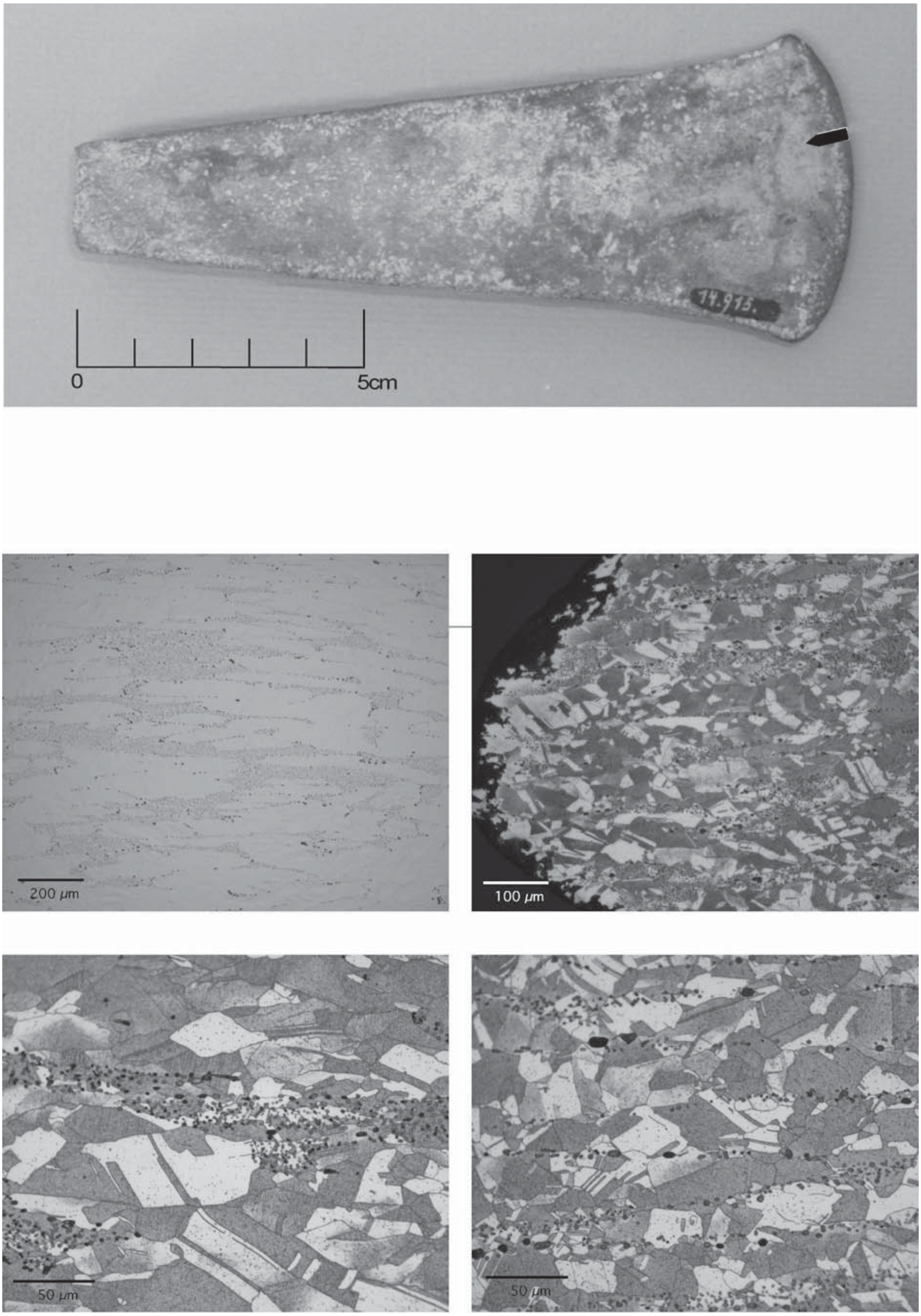


Tab. 39: Sample no. 156.

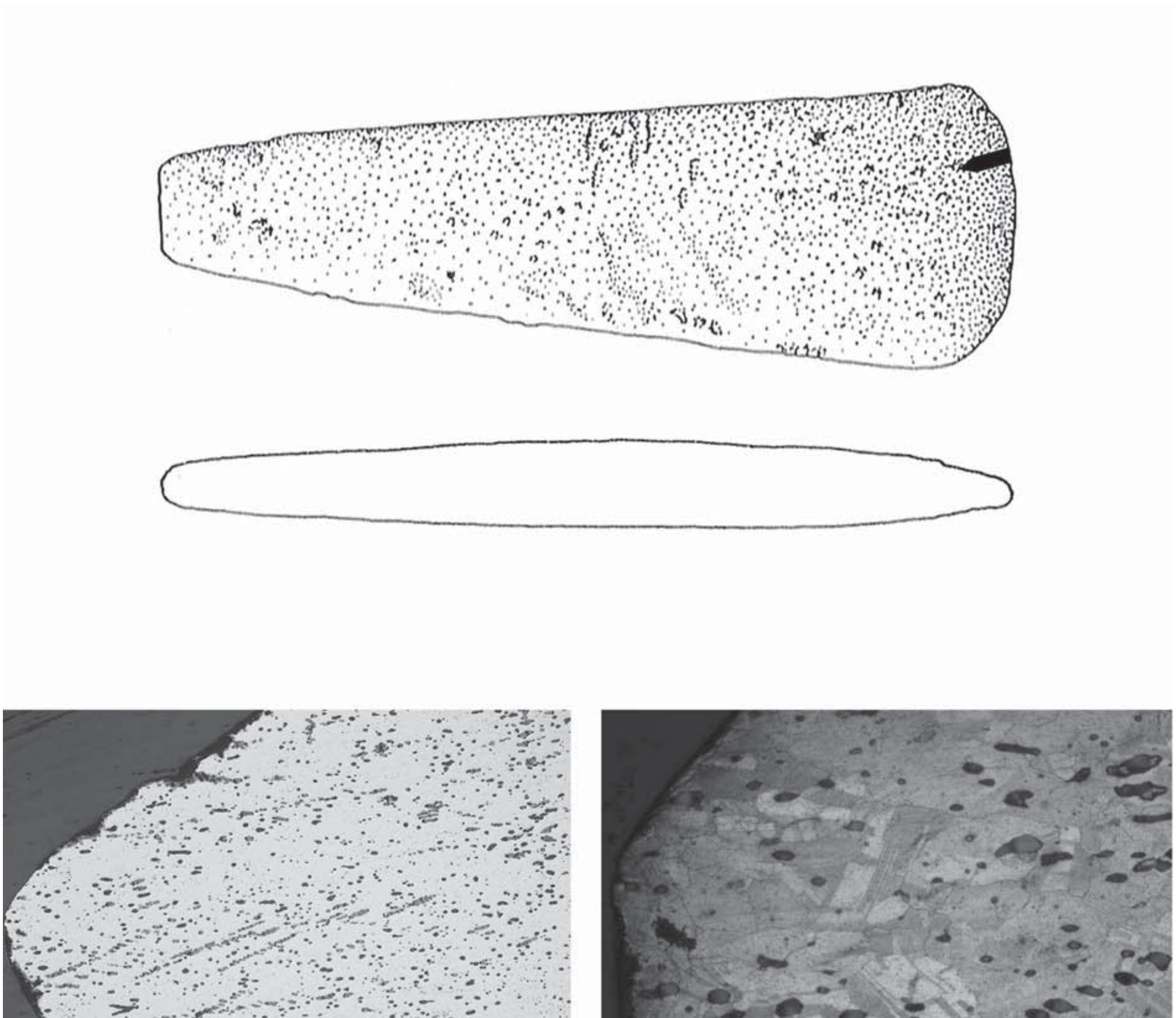
Eneolithic/Copper Age flat axes, horizon 1 (group 2: Hartberg etc.)		
Sample no.	***Origin / context***	***Museum / inv. no.***
49	Beluša SK stray find	Bratislava, Slov. Nár. Múz. 10433 Novotná 1970, 15 no. 24 (schmale Kupferbeile)
77	Hartberg A hoard(?)	Graz, 14915 Mayer 1977, 46 no. 97 (Stollhof, Var. Hartberg)
86	unknown unknown	Wien, Urgesch. Inst., 9017 Mayer 1977, 52 no. 123 (kleine Flachbeile)
103	unknown unknown	Wien, Urgesch. Inst., 9015 Mayer 1977, 46 no. 99 (Stollhof, Var. Hartberg)
106	unknown unknown	Wien, Urgesch. Inst., 9018 Mayer 1977, 52 no. 122 (kleine Flachbeile)
122	Droždín CZ stray find	Olomouc, A 6594 Říhovský 1992, 59 no. 72 (Gr. III, Typ 2a, Var. Bb)
157	Lešná CZ stray find	Brno, 69511 Říhovský 1992, 63 no. 92 (Gr. V, Typ 2a, Var. Bb)



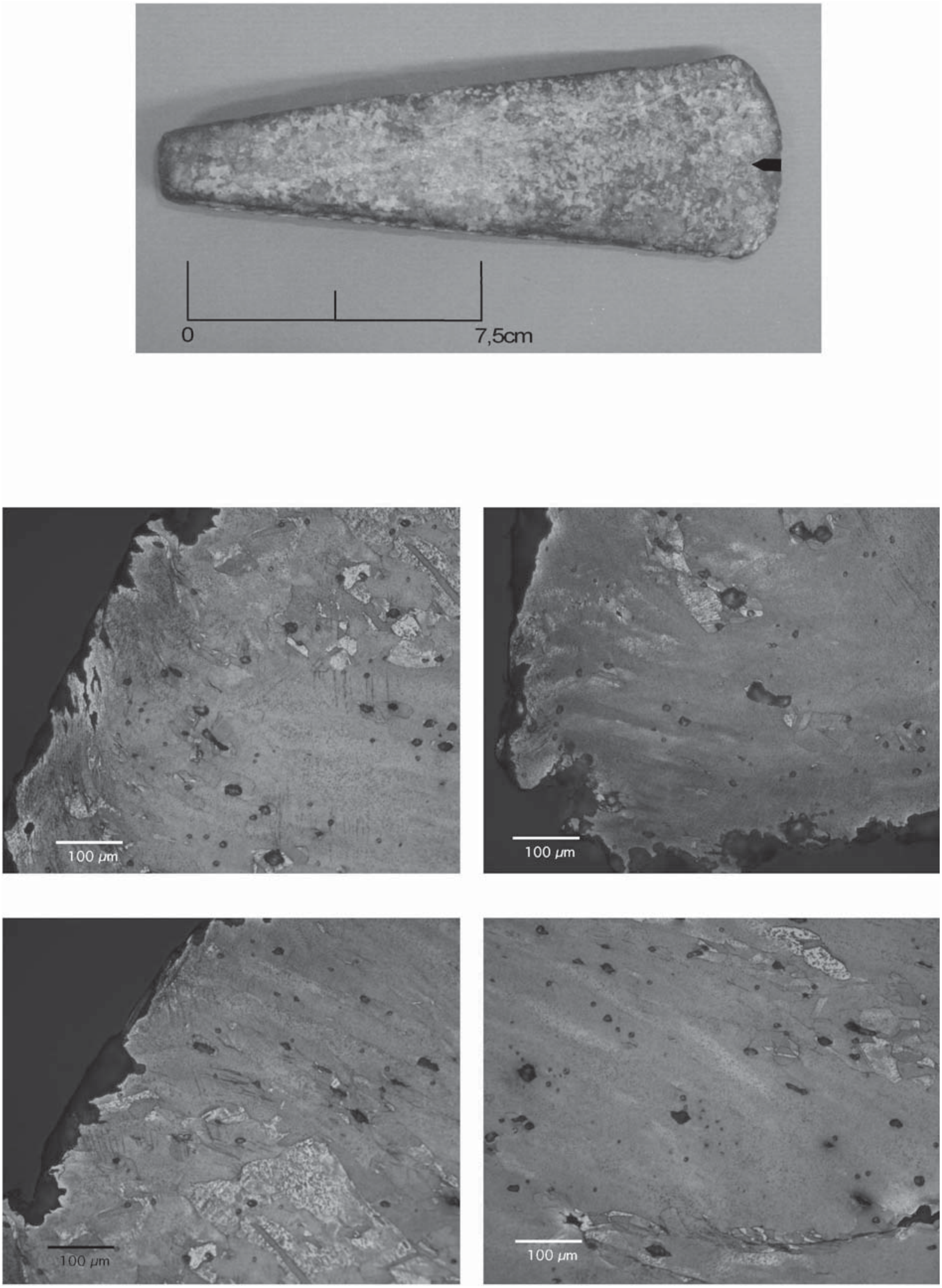
Tab. 40: Sample no. 49 (axe: 1:1).



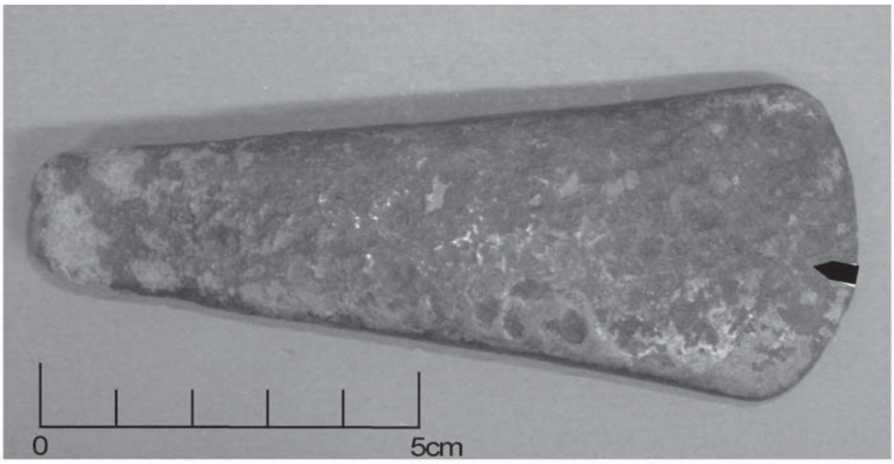
Tab. 41: Sample no. 77.

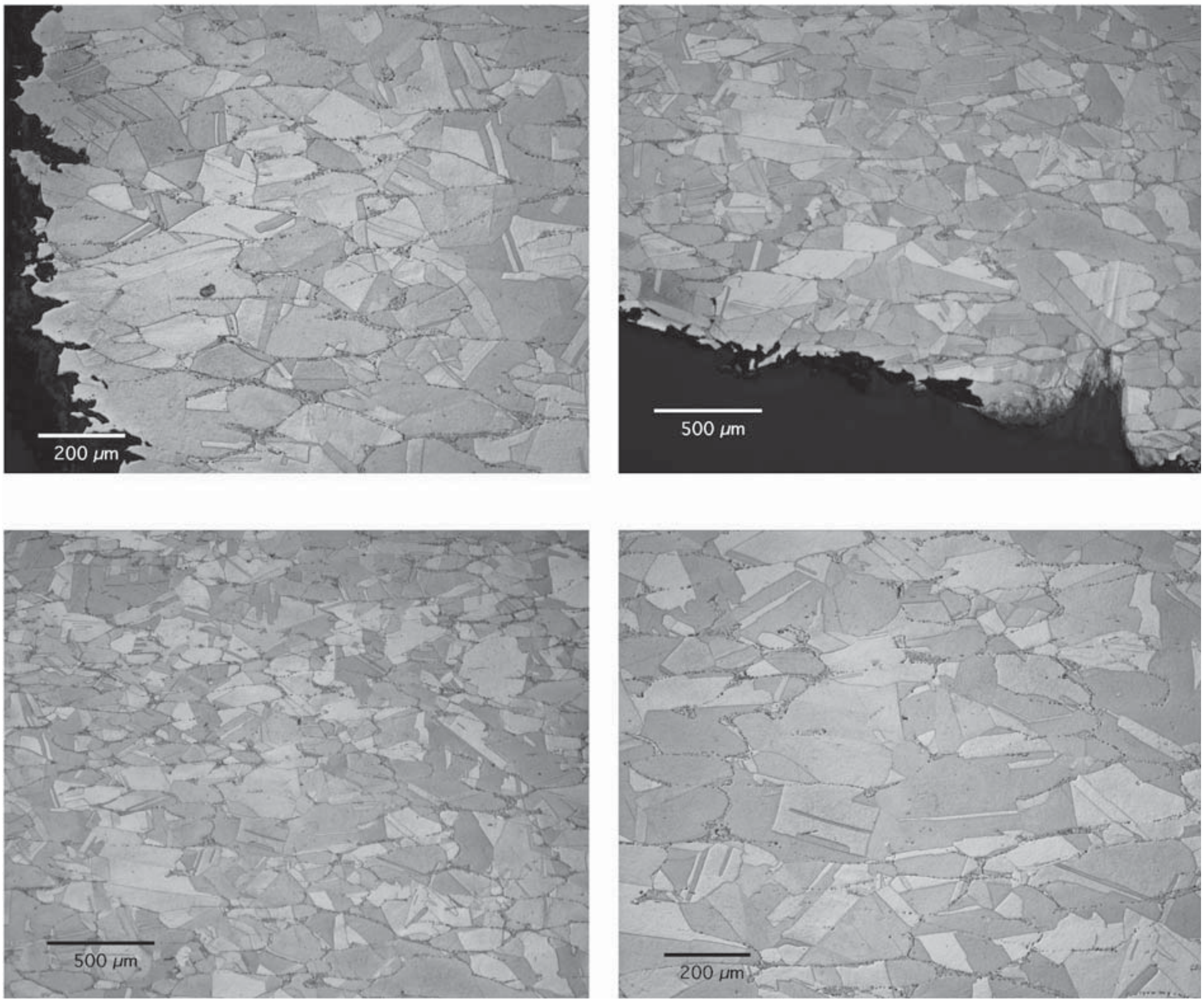


Tab. 42: Sample no. 86 (axe: 1:1).

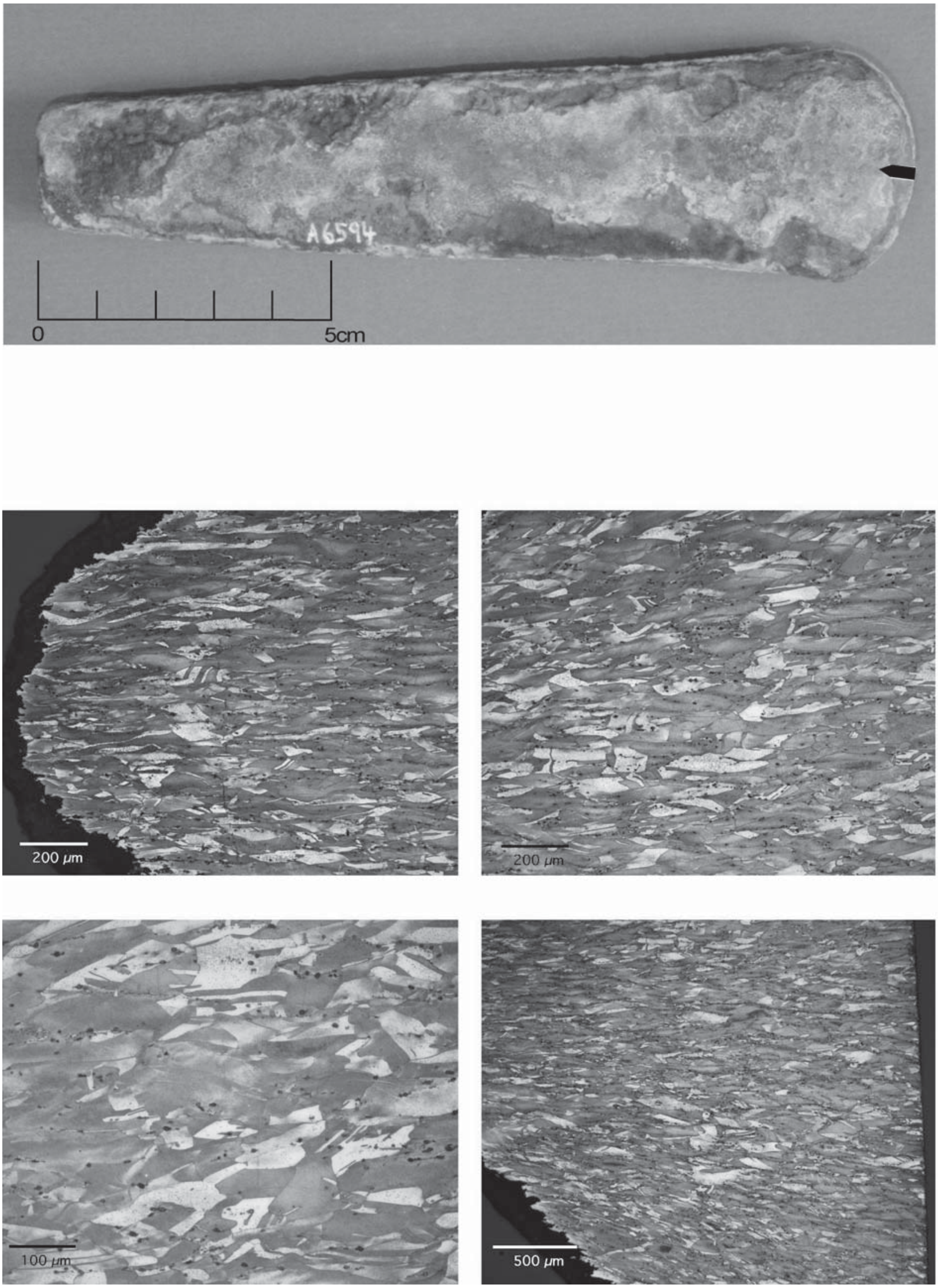


Tab. 43: Sample no. 103.

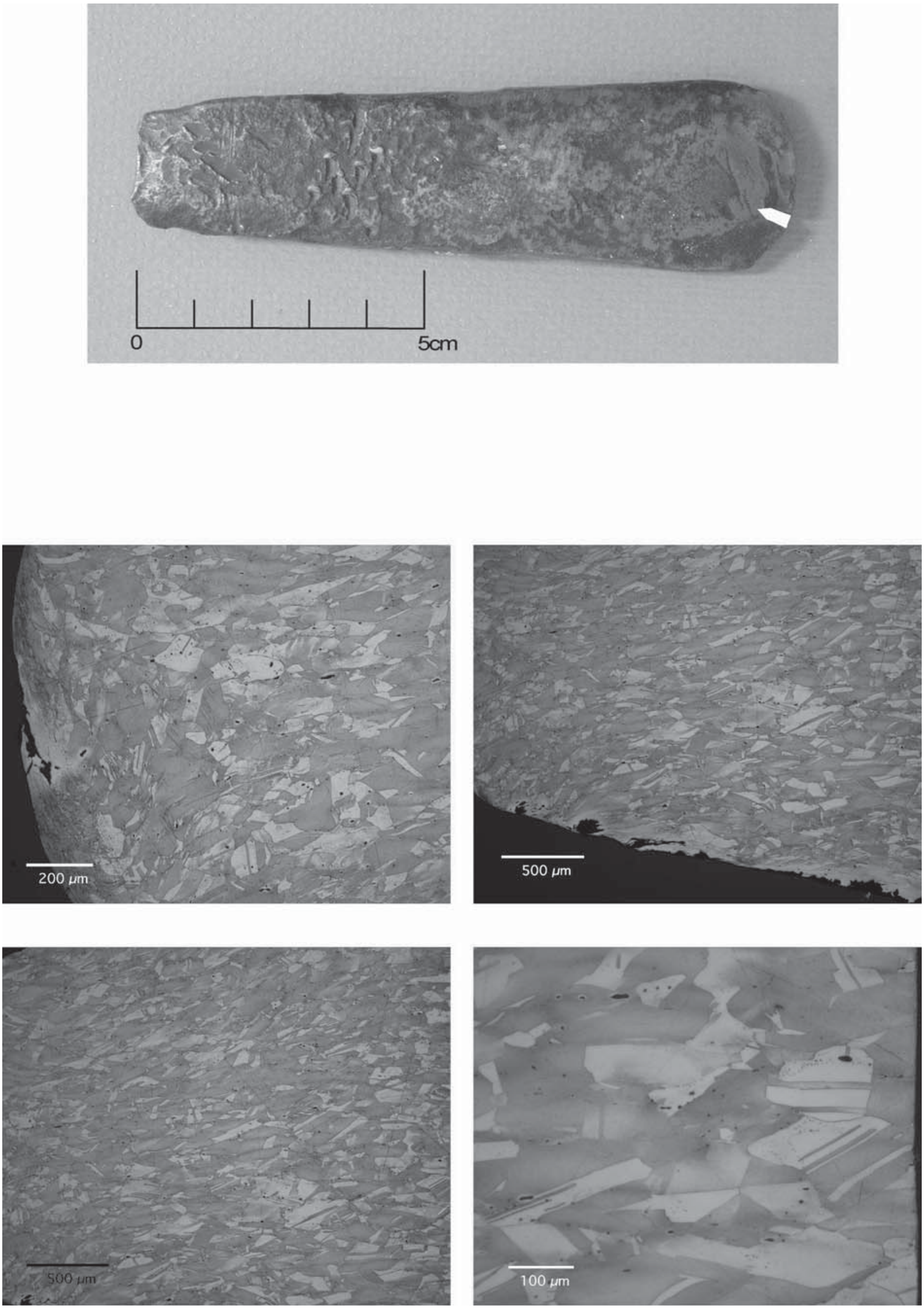




Tab. 44: Sample no. 106.

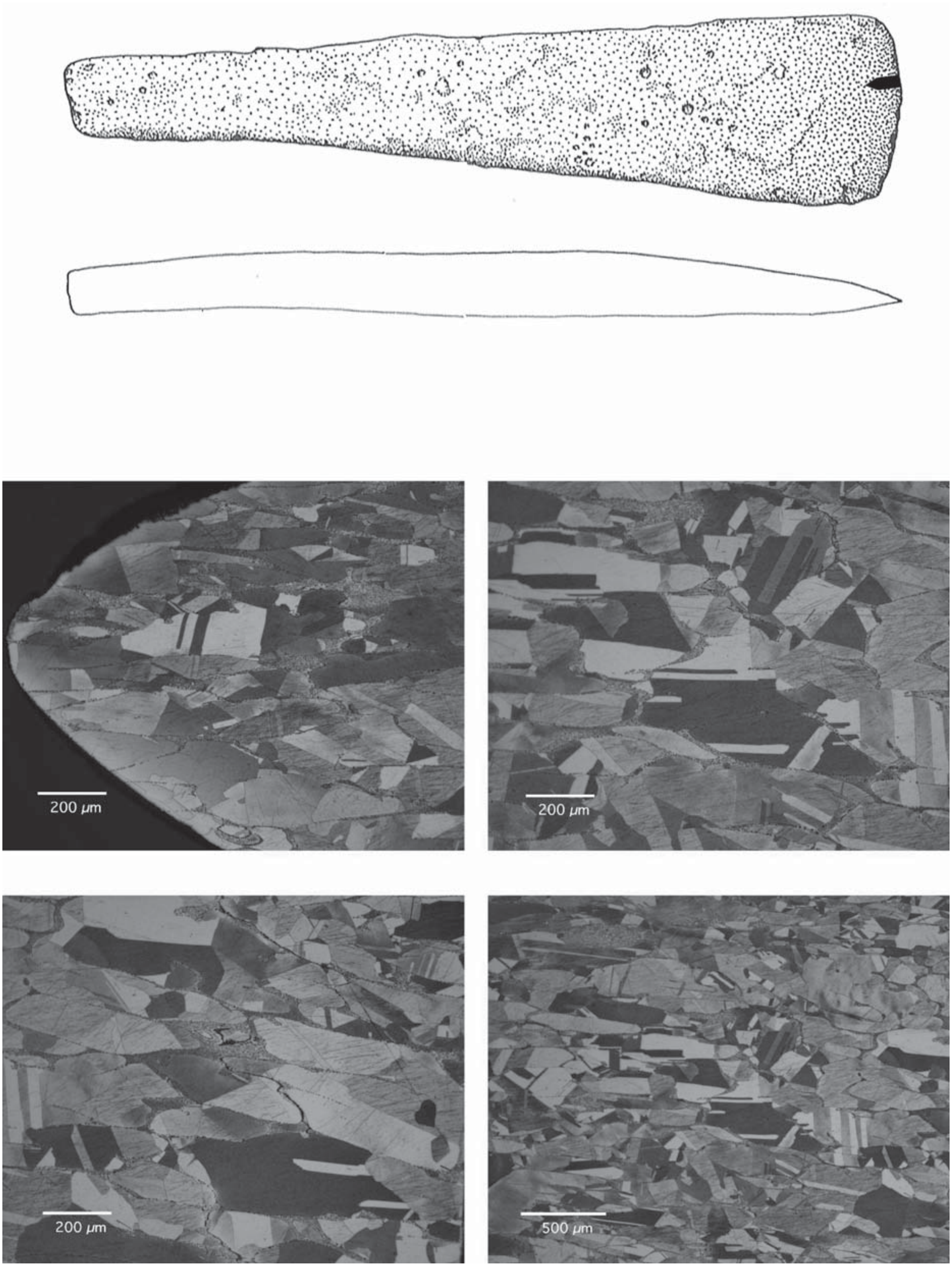


Tab. 45: Sample no. 122.

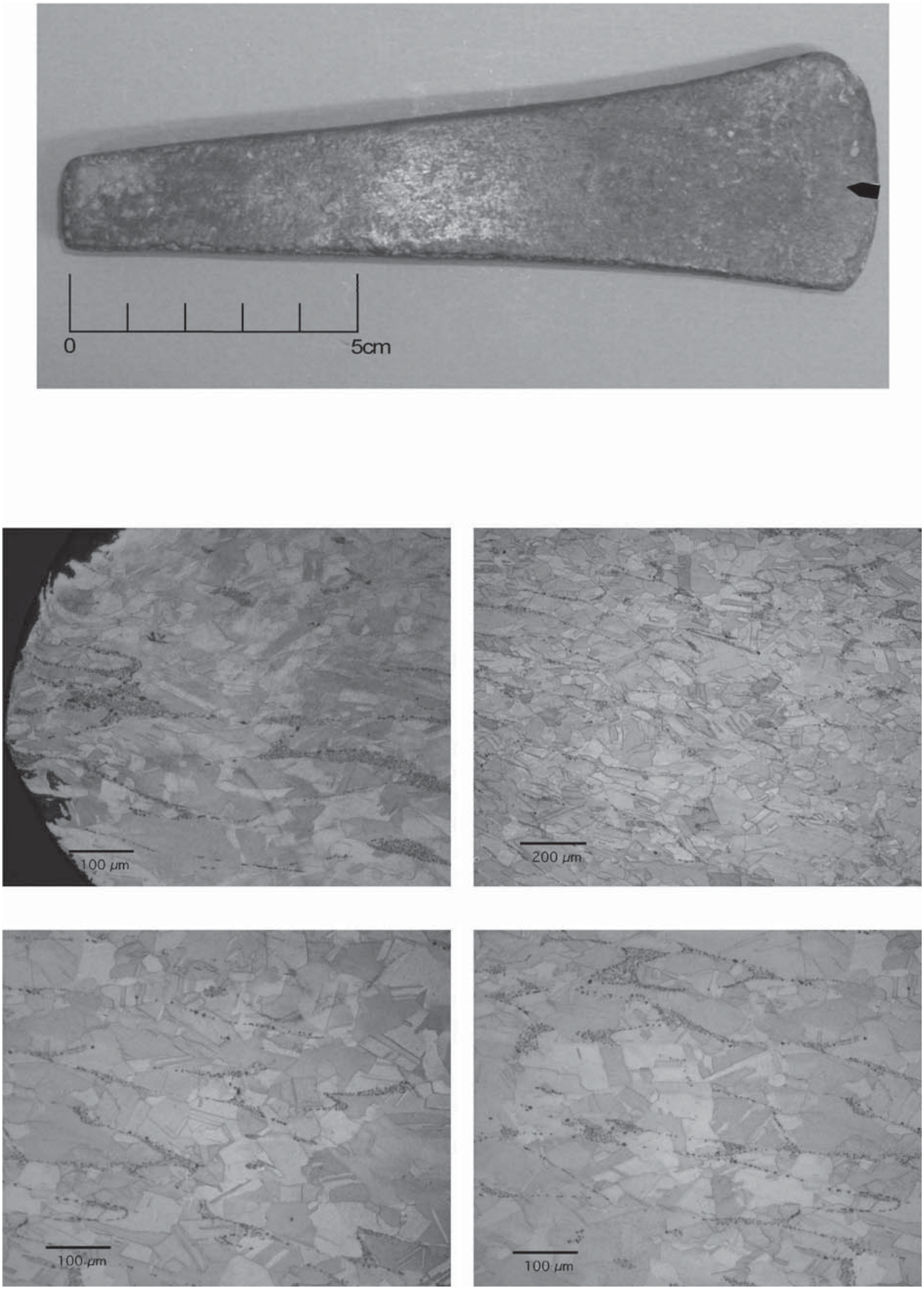


Tab. 46: Sample no. 157.

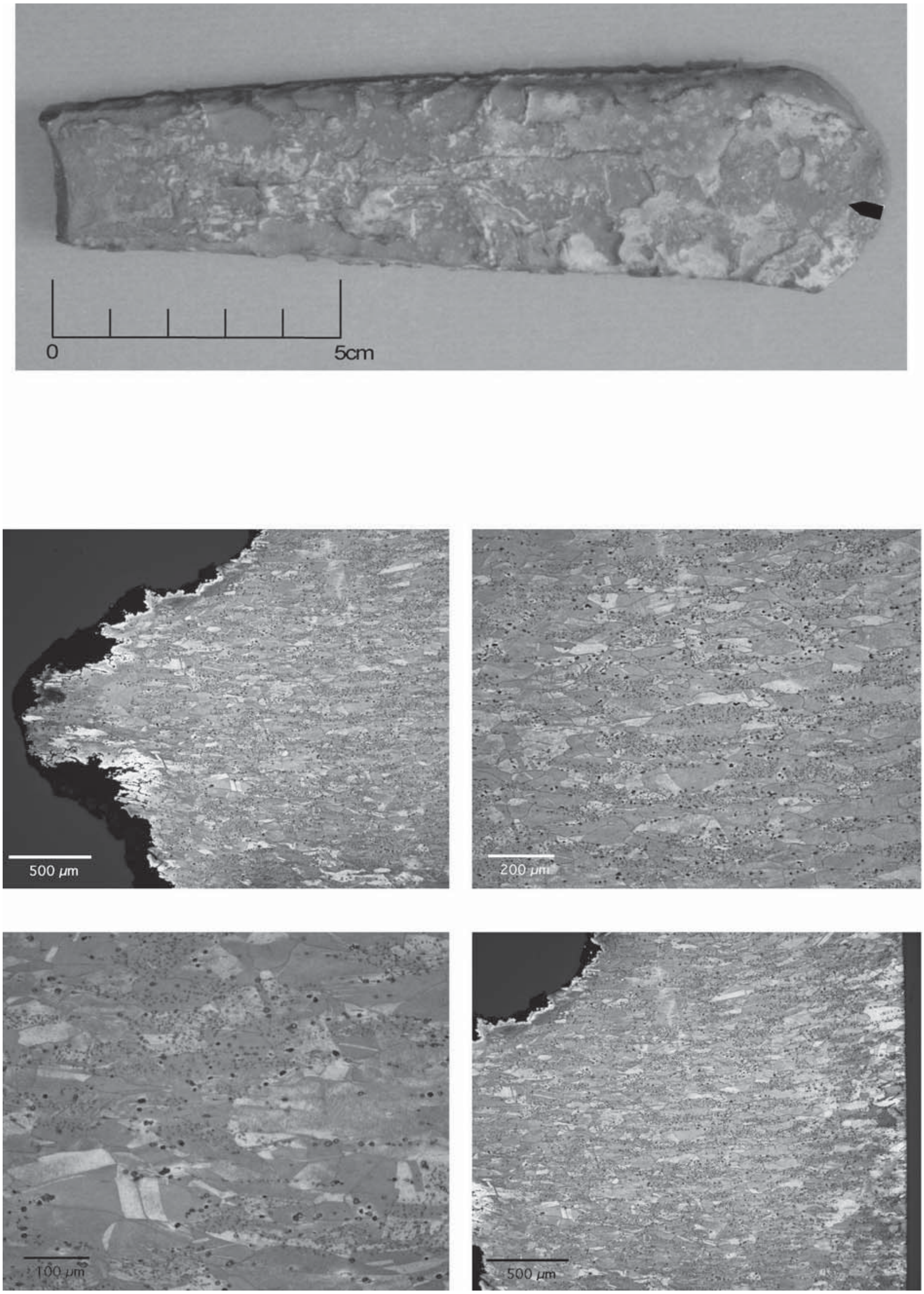
Eneolithic/Copper Age flat axes, horizon 1 (group 3: Szakálhát etc.)		
Sample no.	***Origin / context***	***Museum / inv. no.***
46	Linz A hoard(?) (see sample no. 45)	Linz, A 4796 Mayer 1977, 50 no. 111 (Szakálhát)
108	unknown unknown	Wien, Urgesch. Inst., 9019 Mayer 1977, 50 no. 110 (Szakálhát)
120	Tršice CZ stray find	Olomouc, A 66988 – 4985 Říhovský 1992, 63 no. 90 (Gr. V, Typ 2a, Var. Ab)
121	Slatinice CZ stray find	Olomouc, A 66987 Říhovský 1992, 60 no. 79 (Gr. III, Typ 2a, Var. Bb)



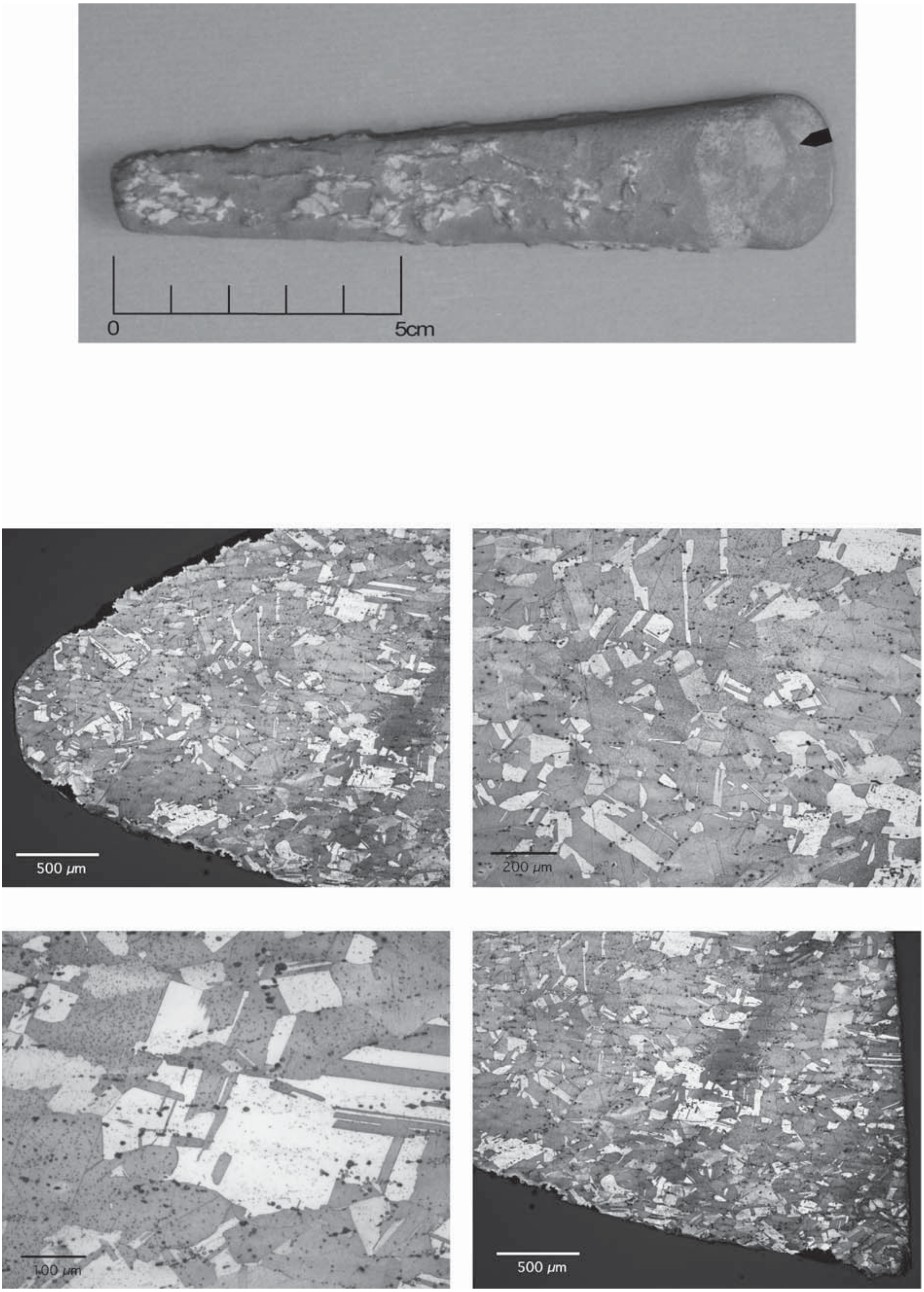
Tab. 47: Sample no. 46 (axe: 3:4).



Tab. 48: Sample no. 108.

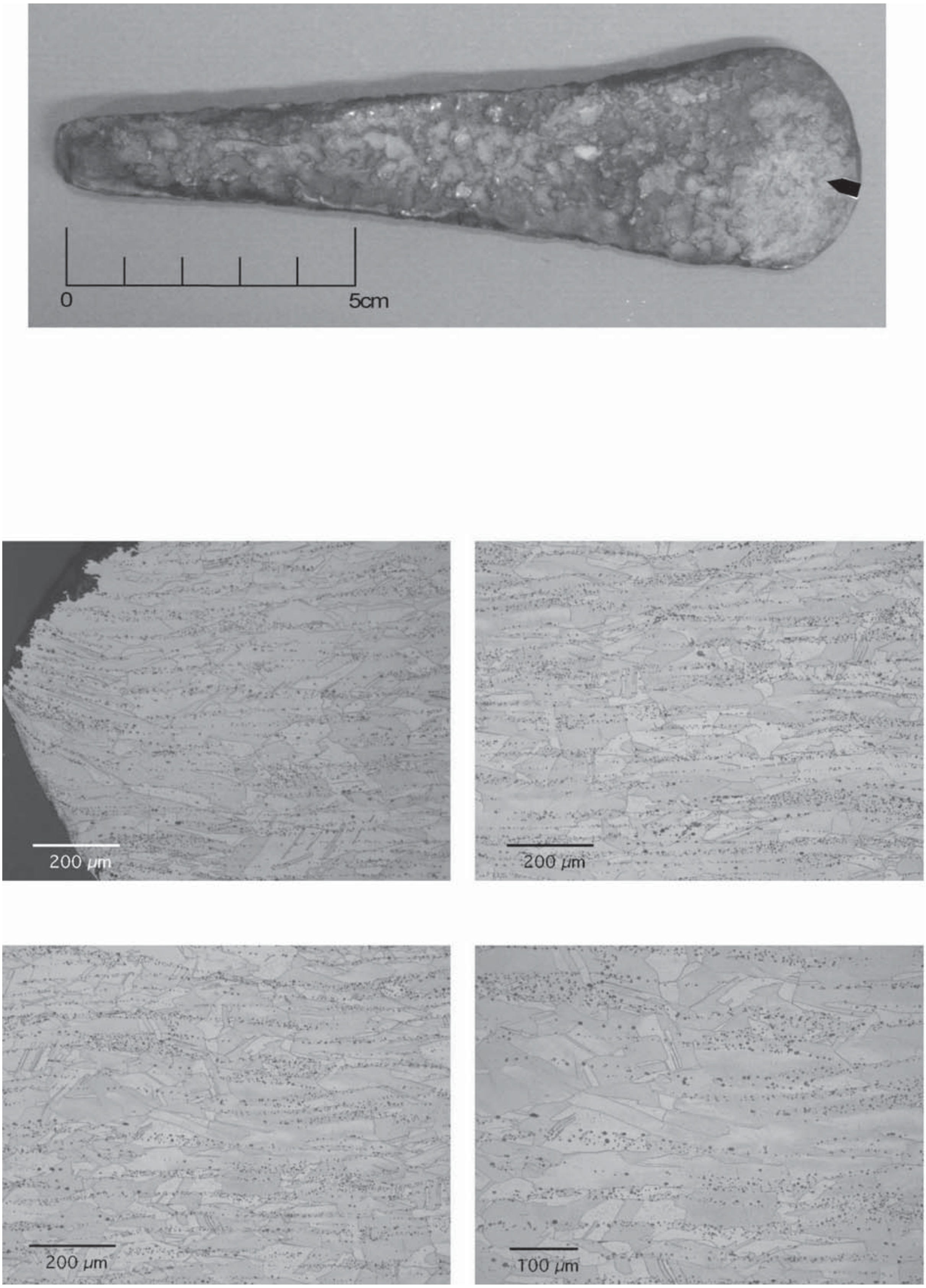


Tab. 49: Sample no. 120.

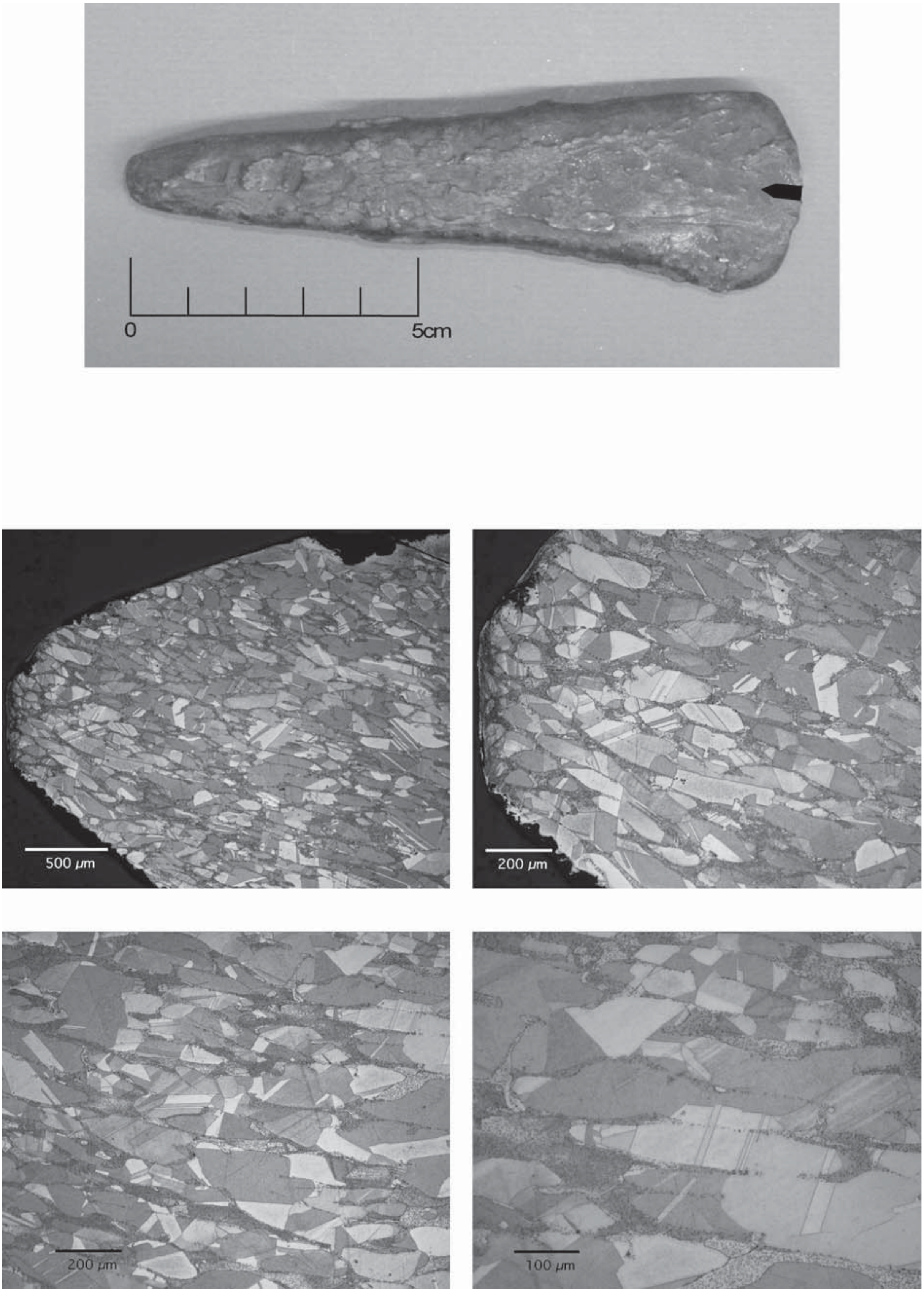


Tab. 50: Sample no. 121.

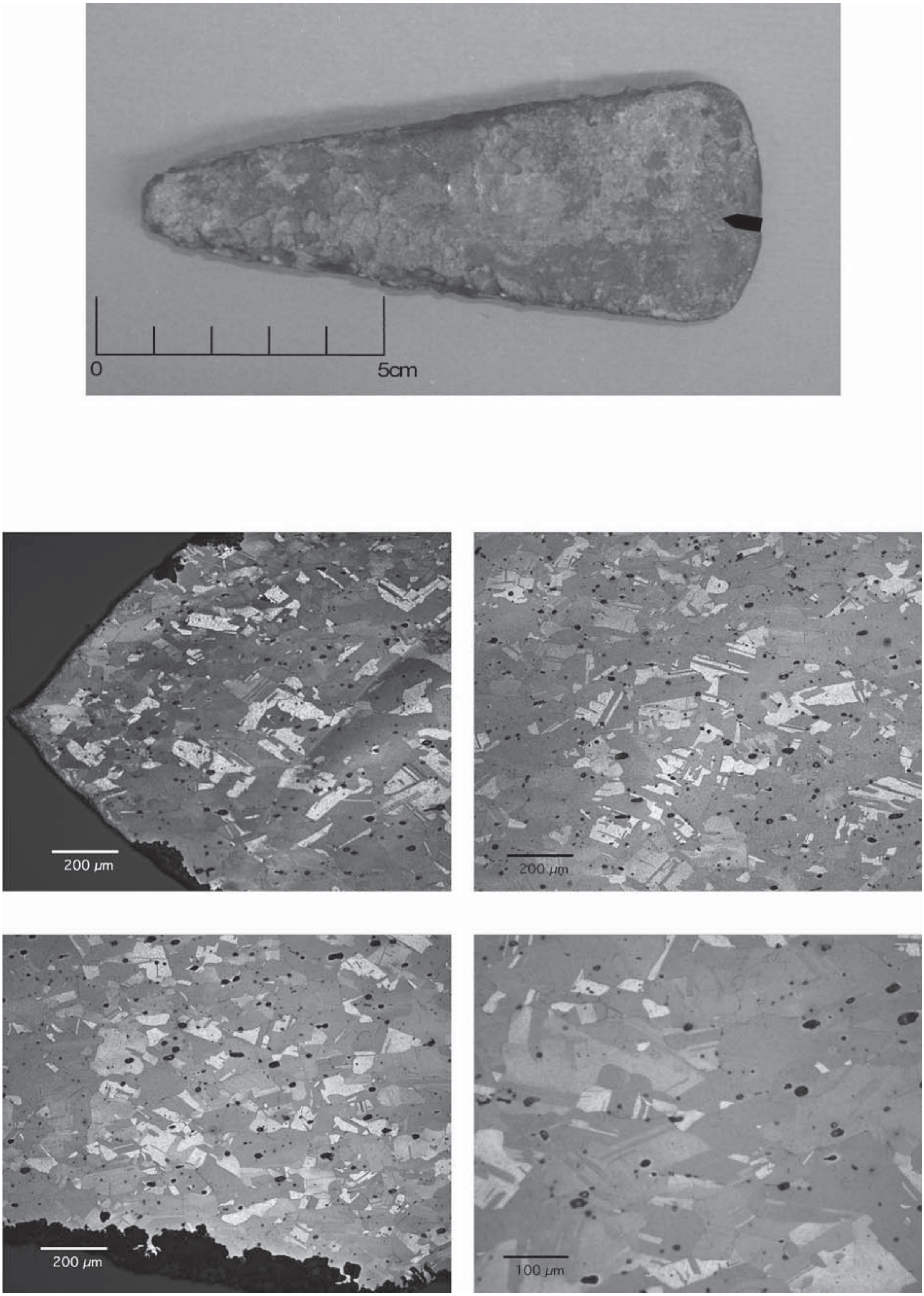
Eneolithic/Copper Age flat axes, horizon 1 (group 4: Split etc.)		
Sample no.	***Origin / context***	***Museum / inv. no.***
92	unknown unknown	Wien, Urgesch. Inst., 9022 Mayer 1977, 51 no. 117 (Split)
109	unknown unknown	Wien, Urgesch. Inst., 9013 Mayer 1977, 51 no. 120 (Split)
110	unknown unknown	Wien, Urgesch. Inst., 9016 Mayer 1977, 52 no. 121 (kleine Flachbeile)



Tab. 51: Sample no. 92.

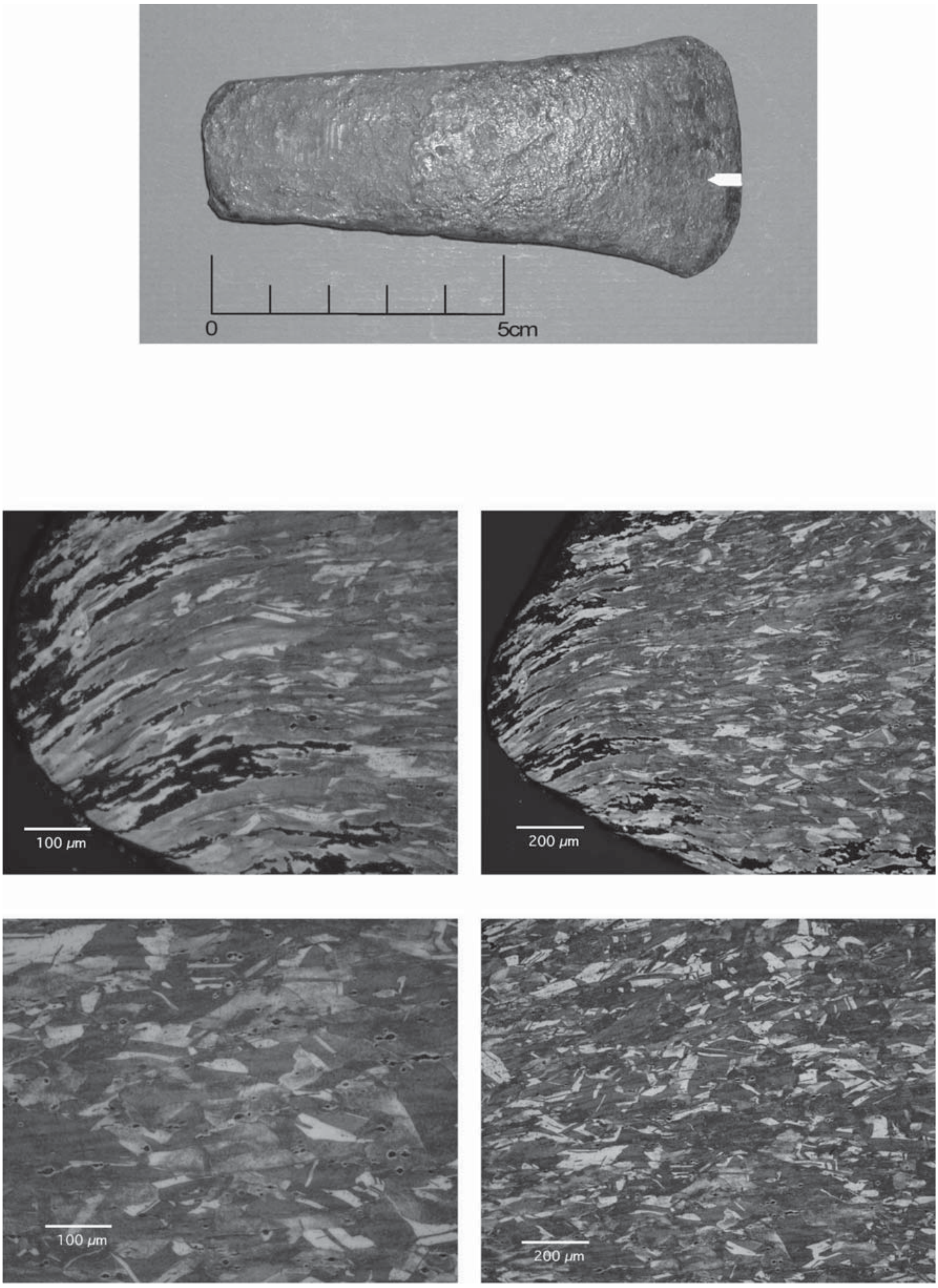


Tab. 52: Sample no. 109.



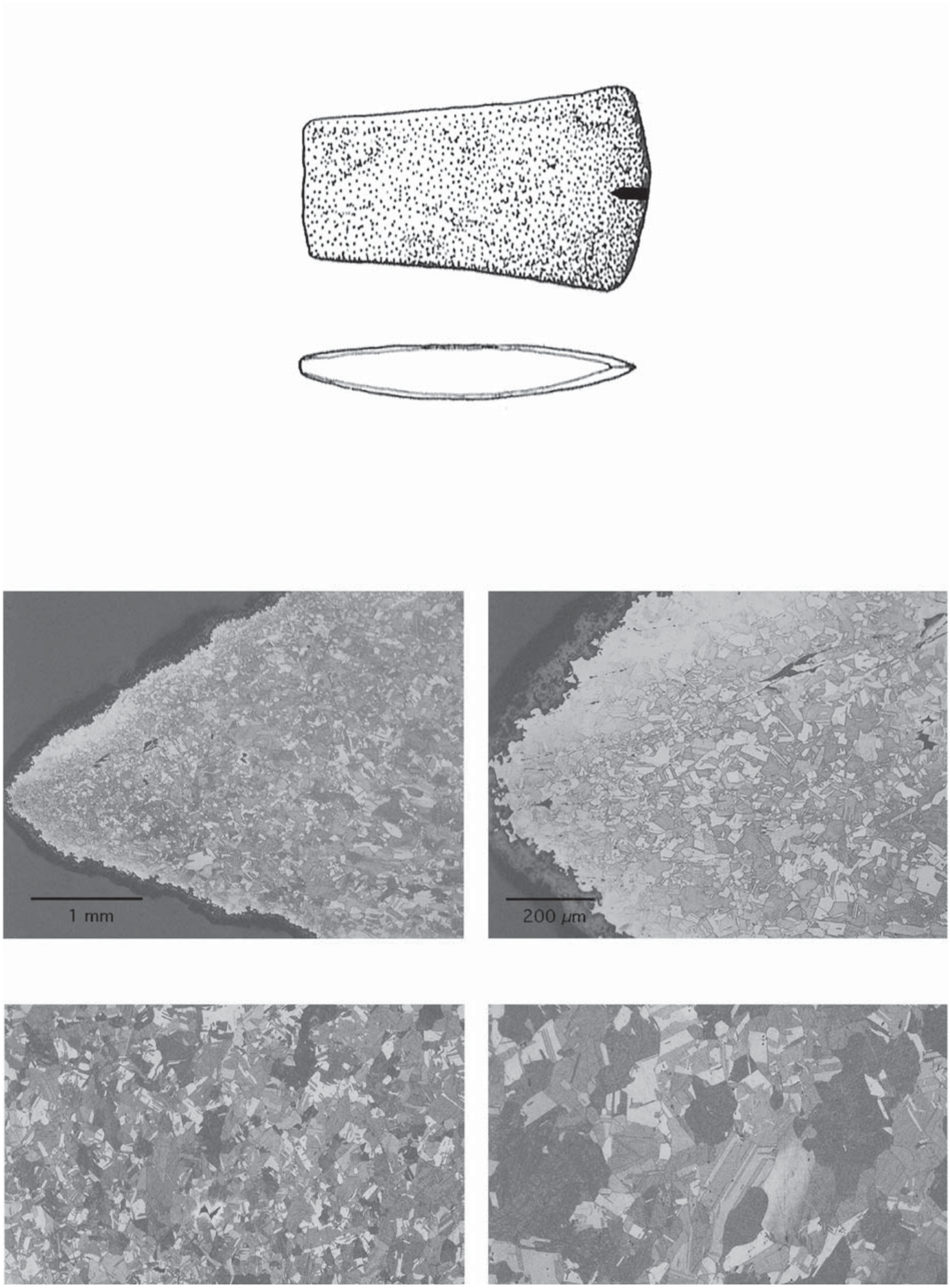
Tab. 53: Sample no. 110.

Eneolithic/Copper Age flat axes, horizon 1 (group 5: Altheim like)		
Sample no.	***Origin / context***	***Museum / inv. no.***
55	Malé Leváre SK hoard (see sample no. 52)	Bratislava, Slov. Nár. Múz. 8460 Novotná 1970, 14 no. 2 (schmale Kupferbeile)

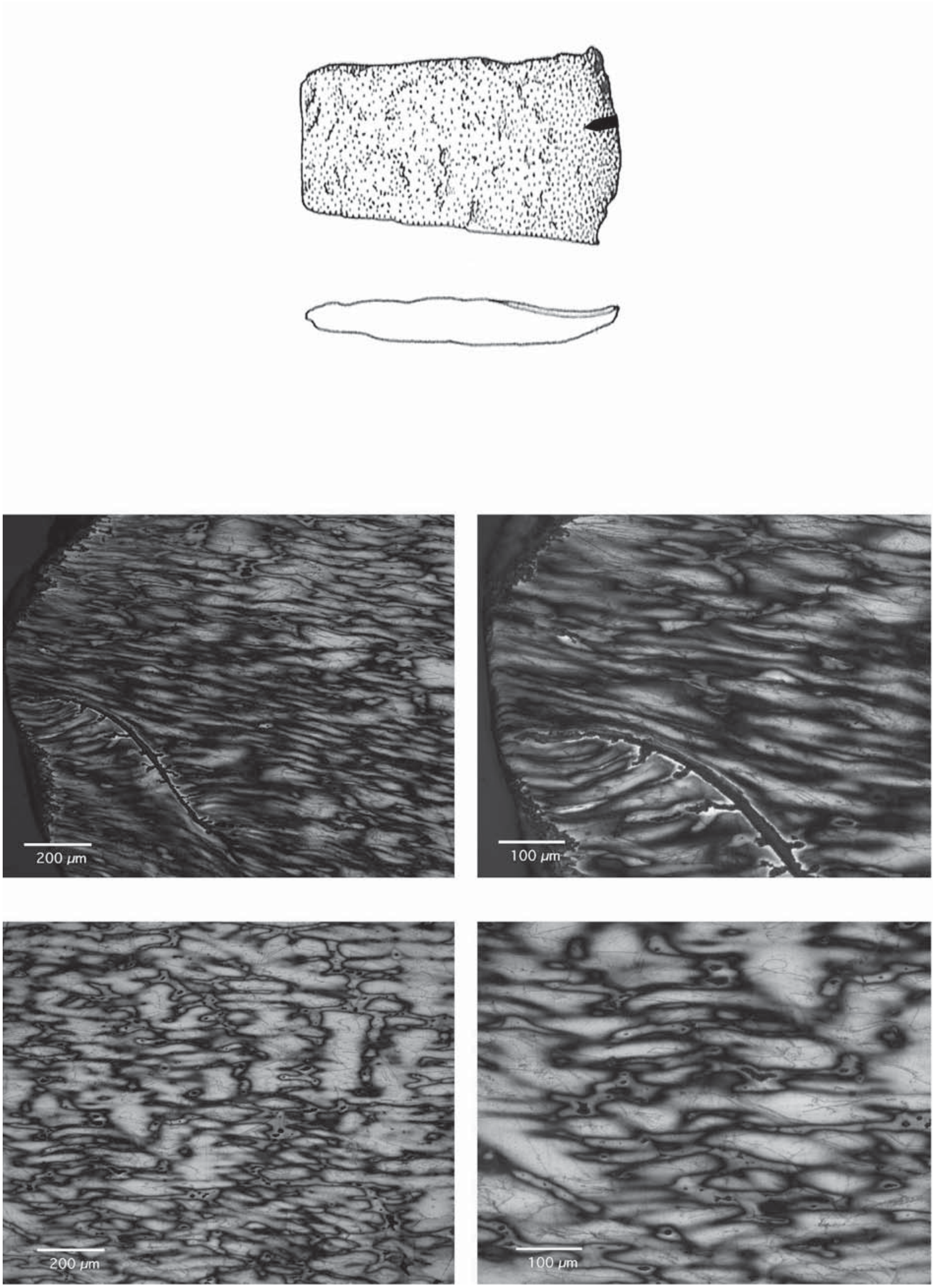


Tab. 54: Sample no. 55.

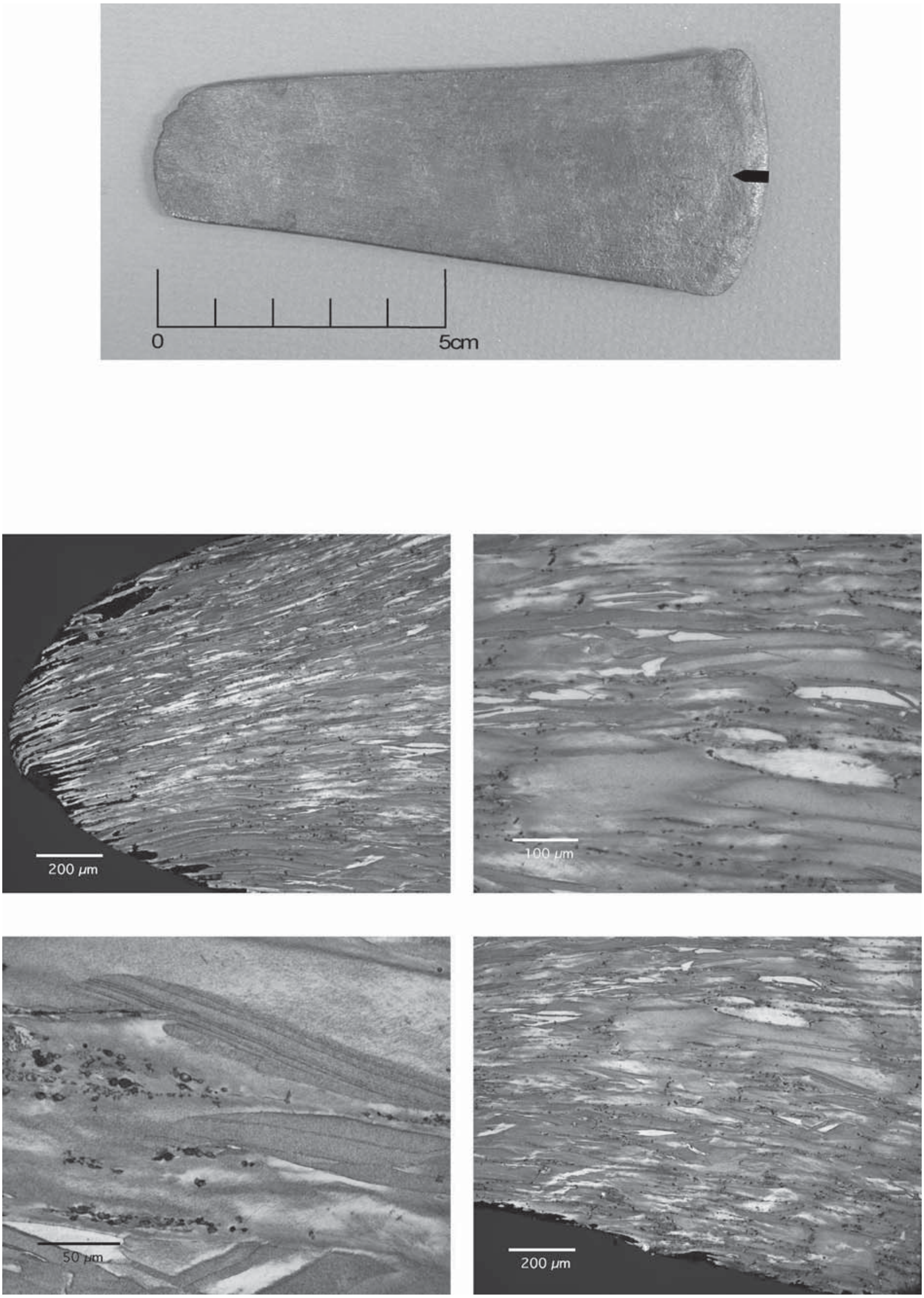
Eneolithic/Copper Age flat axes, horizon 2 (type Altheim)		
Sample no.	***Origin / context***	***Museum / inv. no.***
76	Pöls A settlement	Graz, 11550 Mayer 1977, 56 no. 157
81	unknown unknown	Wien, Urgesch. Inst., 9006 Mayer 1977, 56 no. 159
130	Brno-Líšeň CZ hoard	Brno 107133 Říhovský 1992, 68 no. 117 (Gr. VI, Typ 2b, Var. Aa)
134	Džbánice CZ stray find	Brno Říhovský 1992, 68 no. 119 (Gr. VI, Typ 2b, Var. Bb)
136	Prace CZ hoard(?)	Brno, 69520 Říhovský 1992, 68 no. 120 (Gr. VI, Typ 2b, Var. Bb)
142	Prace CZ hoard(?)	Brno, 69519 Říhovský 1992, 69 no. 124 (Gr. VI, Typ 2d, Var. Bb)
143	Kroměříž-Kotojedy CZ stray find	Brno, 69522 Říhovský 1992, 69 no. 121 (Gr. VI, Typ 2d, Var. Bb)
147	Vevčice CZ hoard(?)	Brno, 69524 Říhovský 1992, 68 no. 116 (Gr. VI, Typ 2a, Var. Bc)
155	Senorady CZ stray find/settlement	Brno, 51098 Říhovský 1992, 69 no. 125 (Gr. VI, Typ 2d, Var. Bb)
207	Gossel D stray find	Weimar, 7954/97



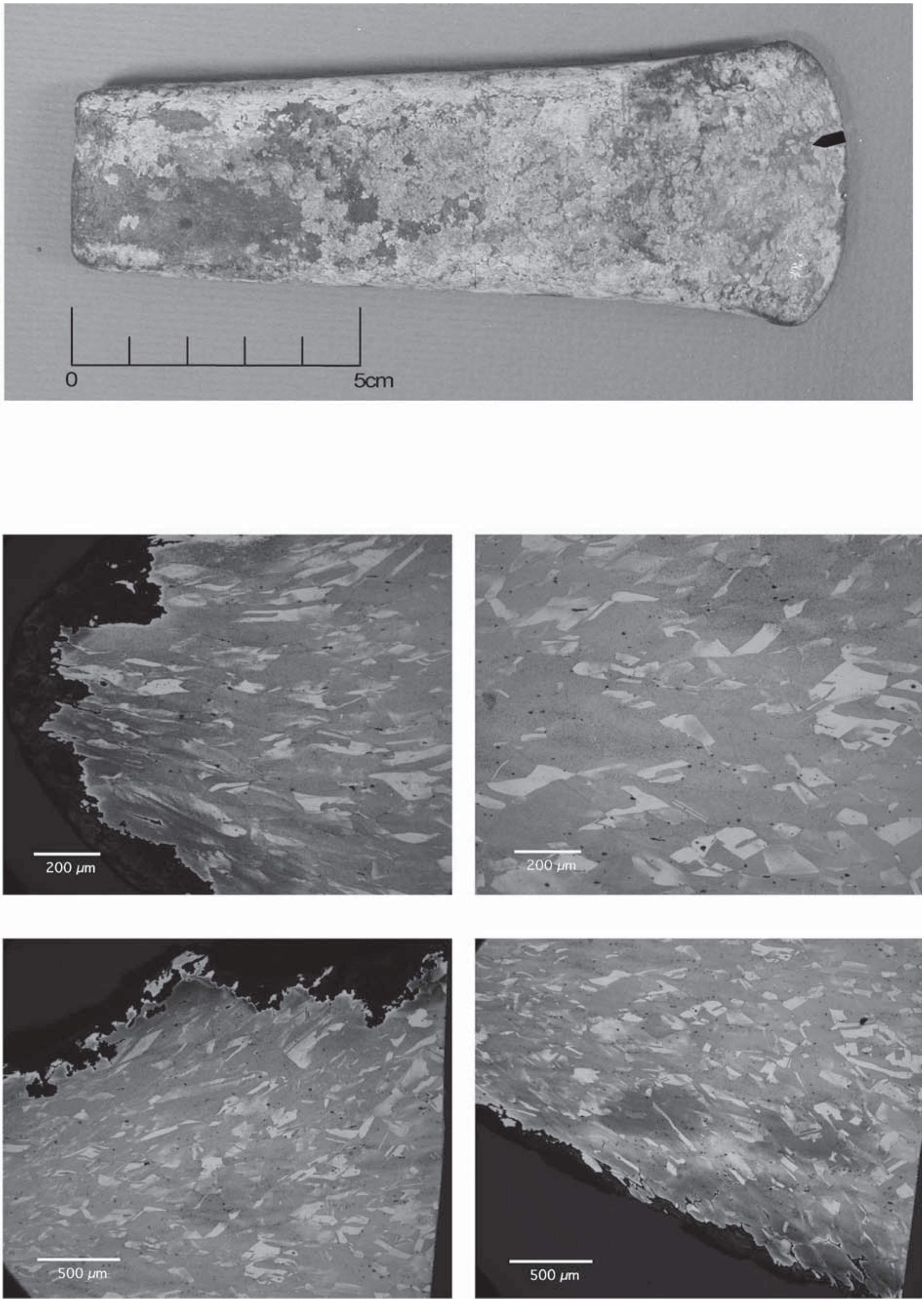
Tab. 55: Sample no. 76 (axe: 1:1).



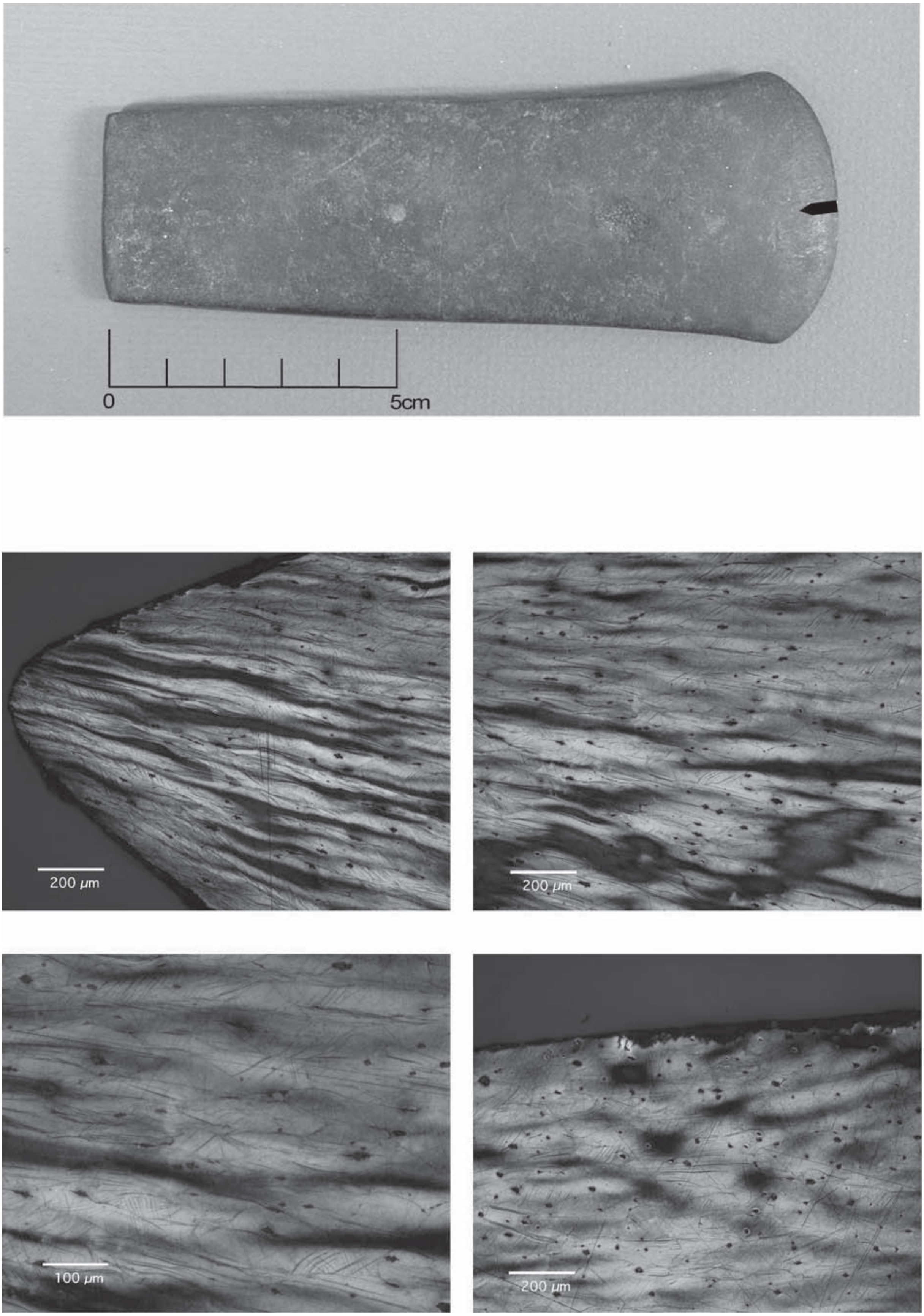
Tab. 56: Sample no. 81 (axe: 1:1).



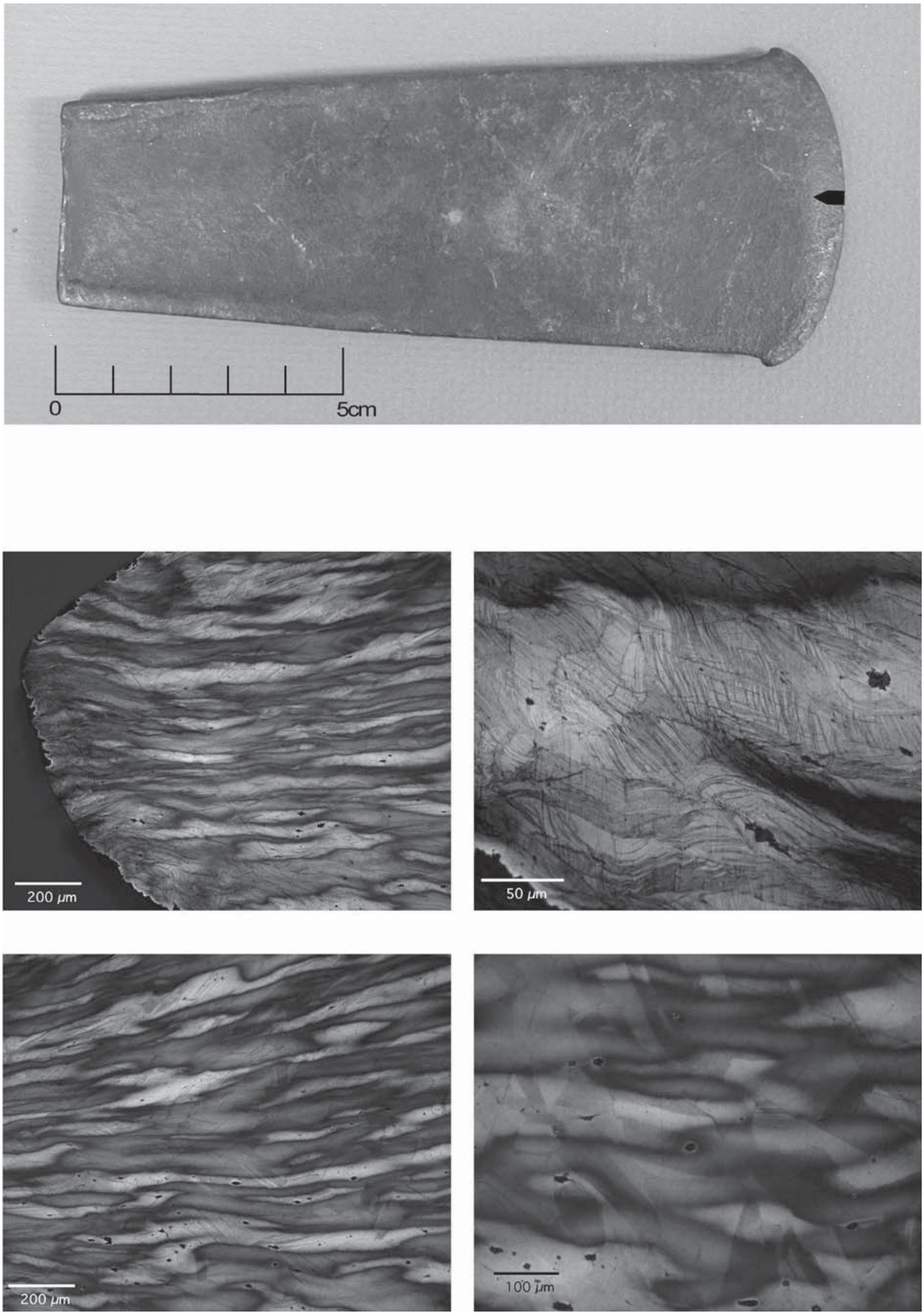
Tab. 57: Sample no. 130.



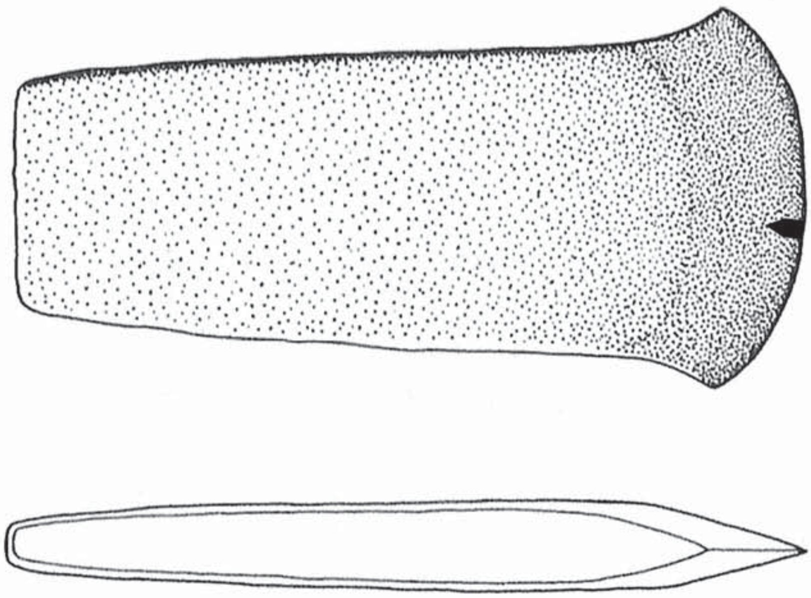
Tab. 58: Sample no. 134.

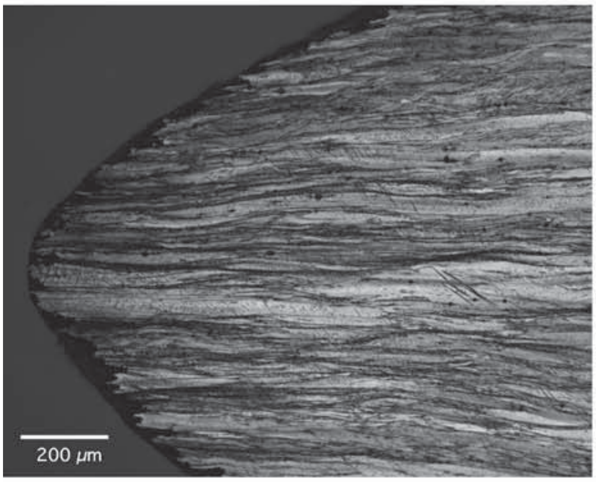


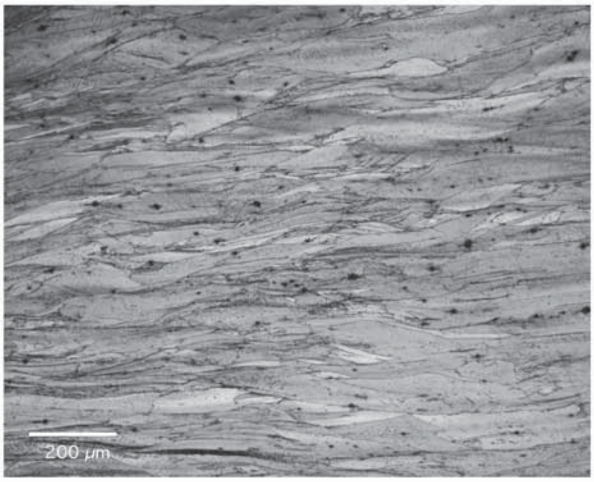
Tab. 59: Sample no. 136.

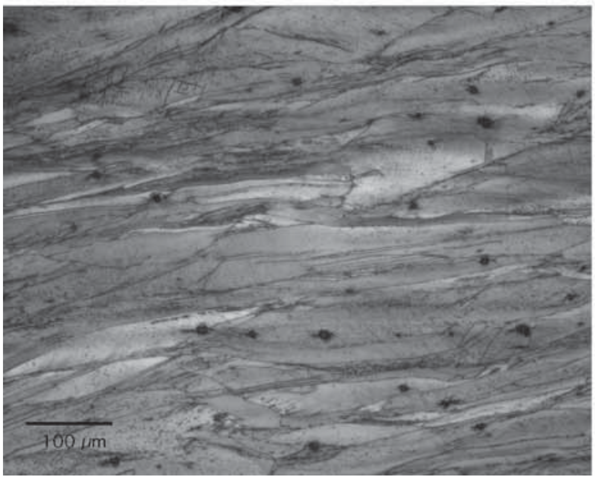


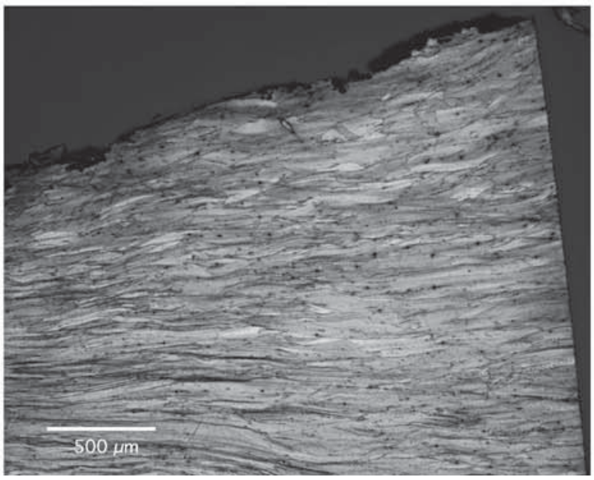
Tab. 60: Sample no. 142.



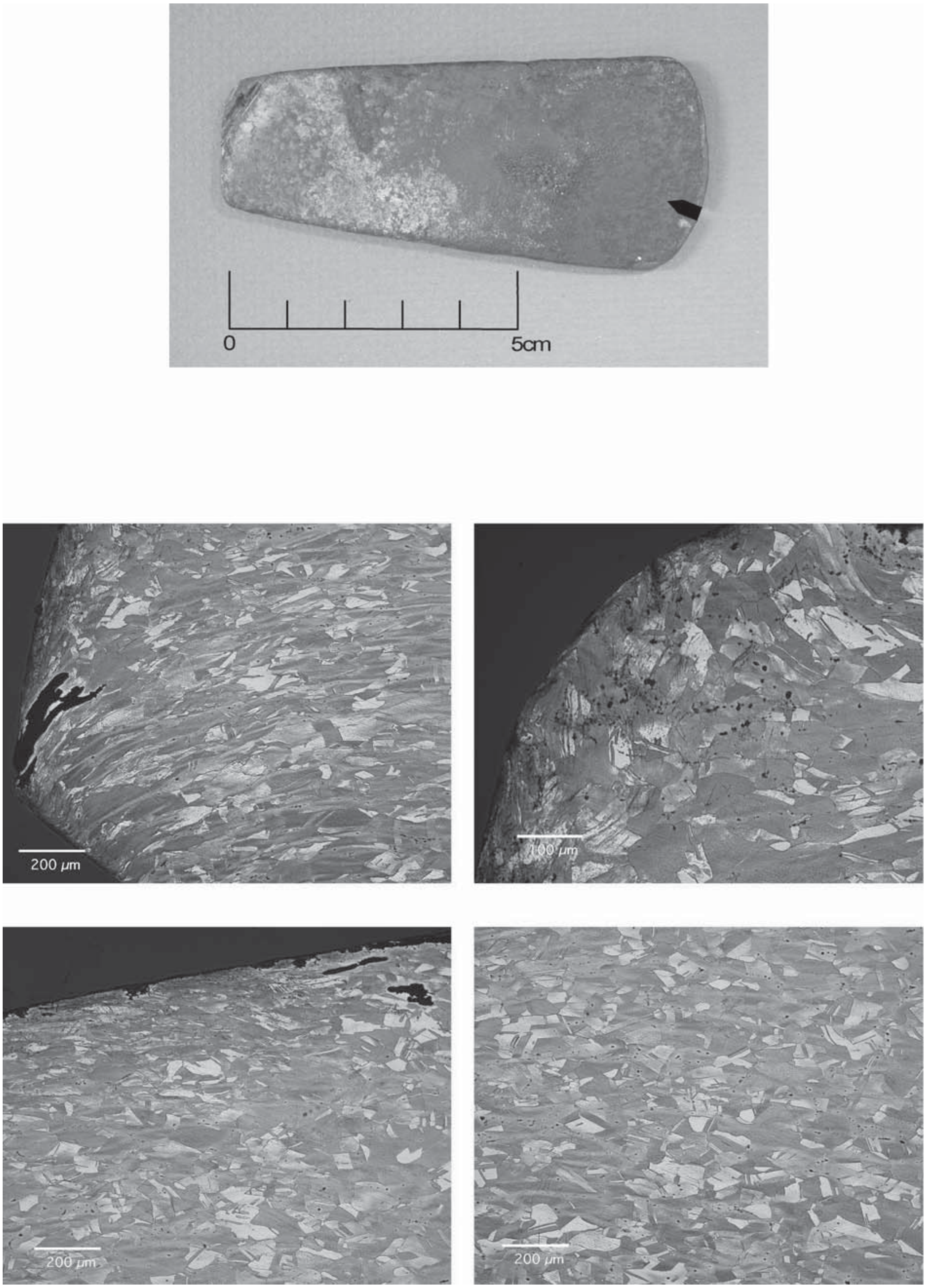




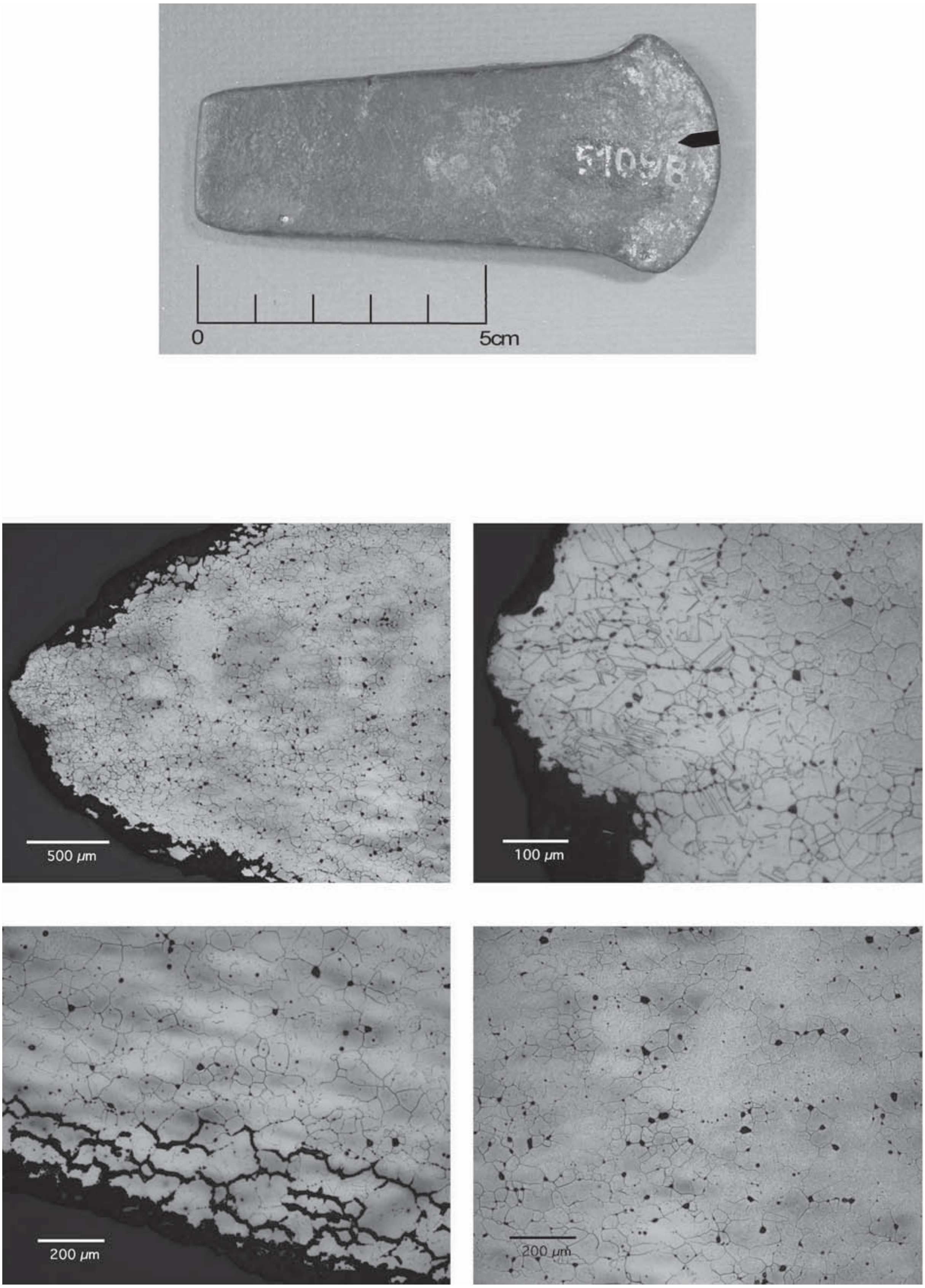




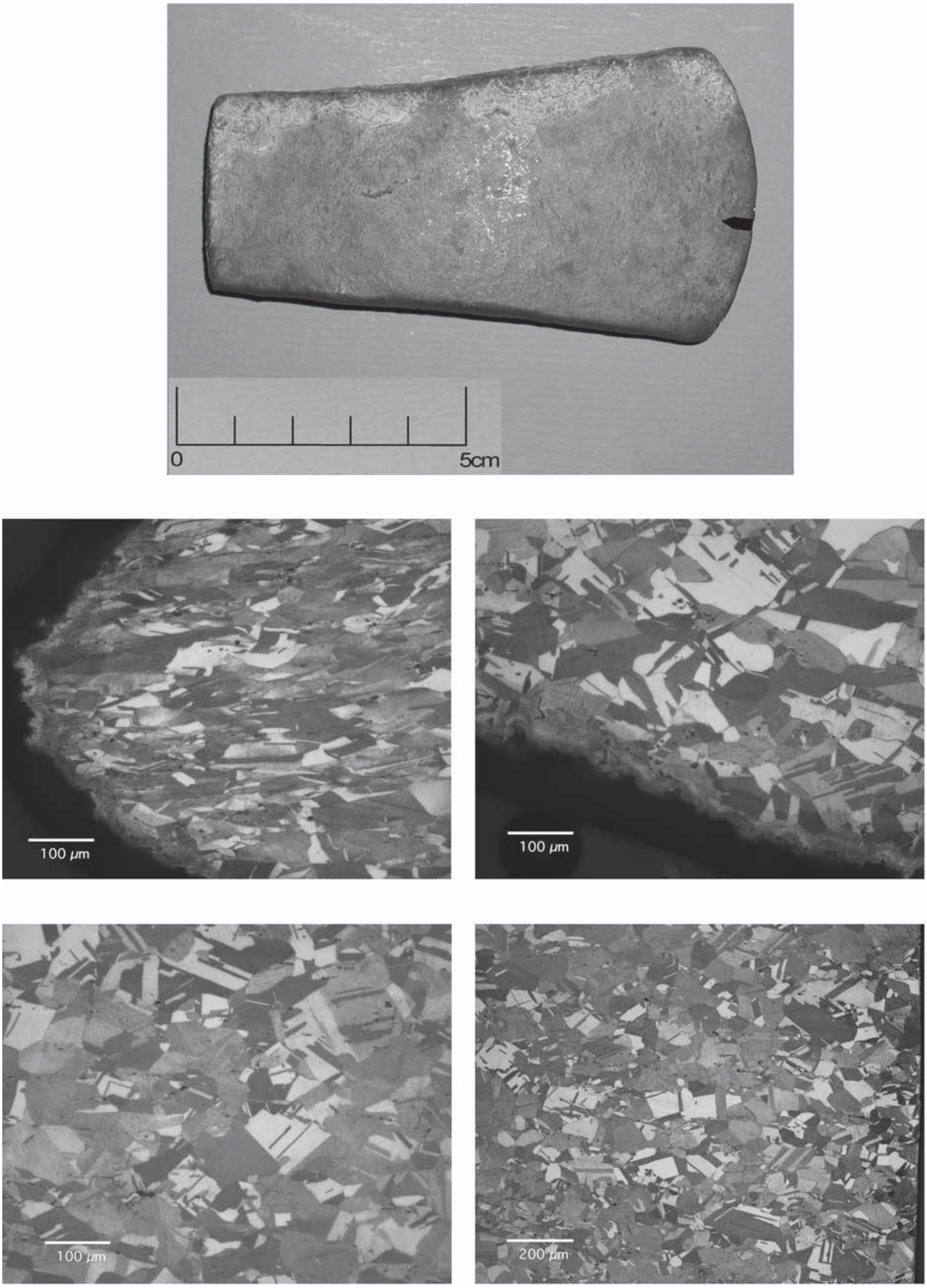
Tab. 61: Sample no. 143 (axe: 1:1).



Tab. 62: Sample no. 147.

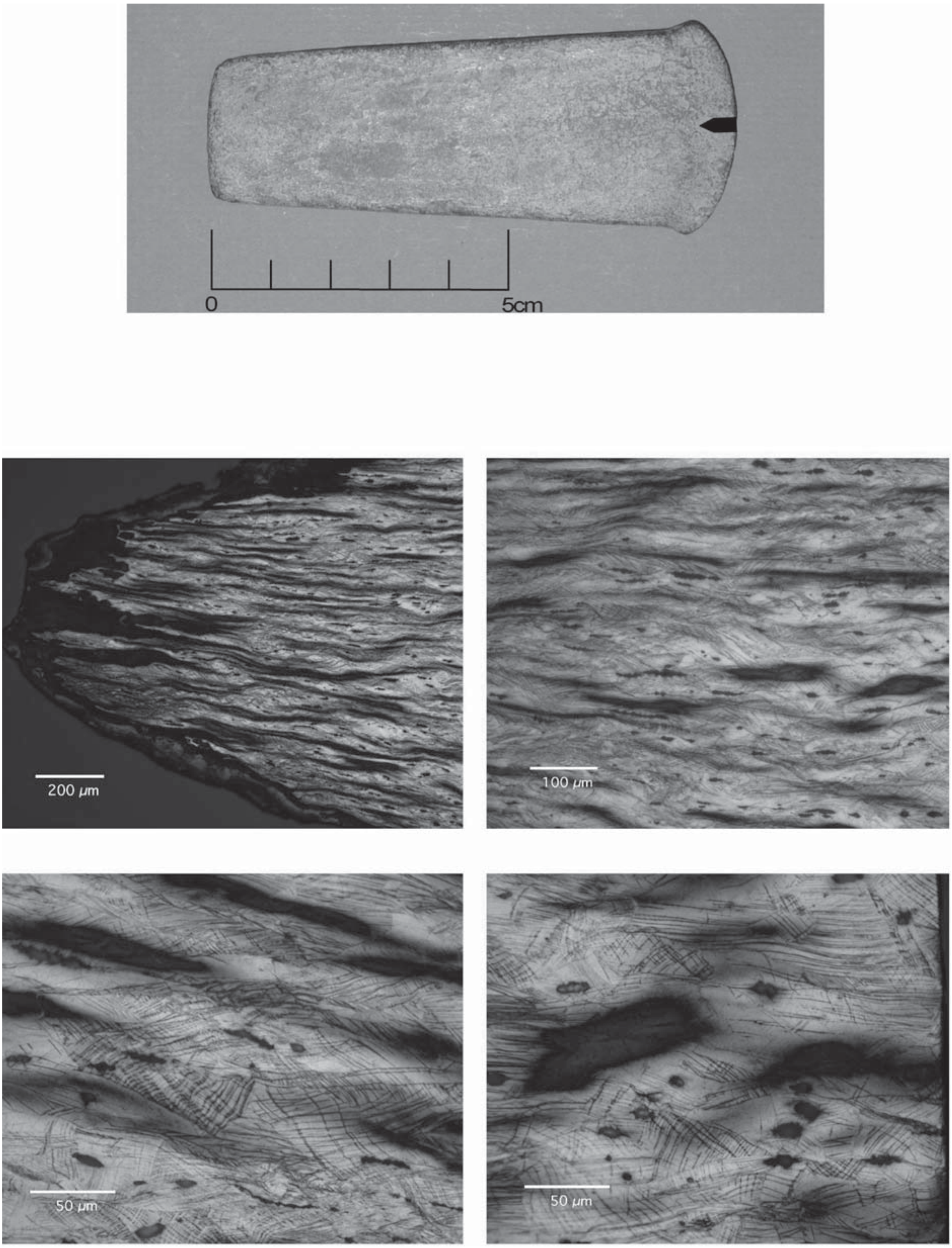


Tab. 63: Sample no. 155.

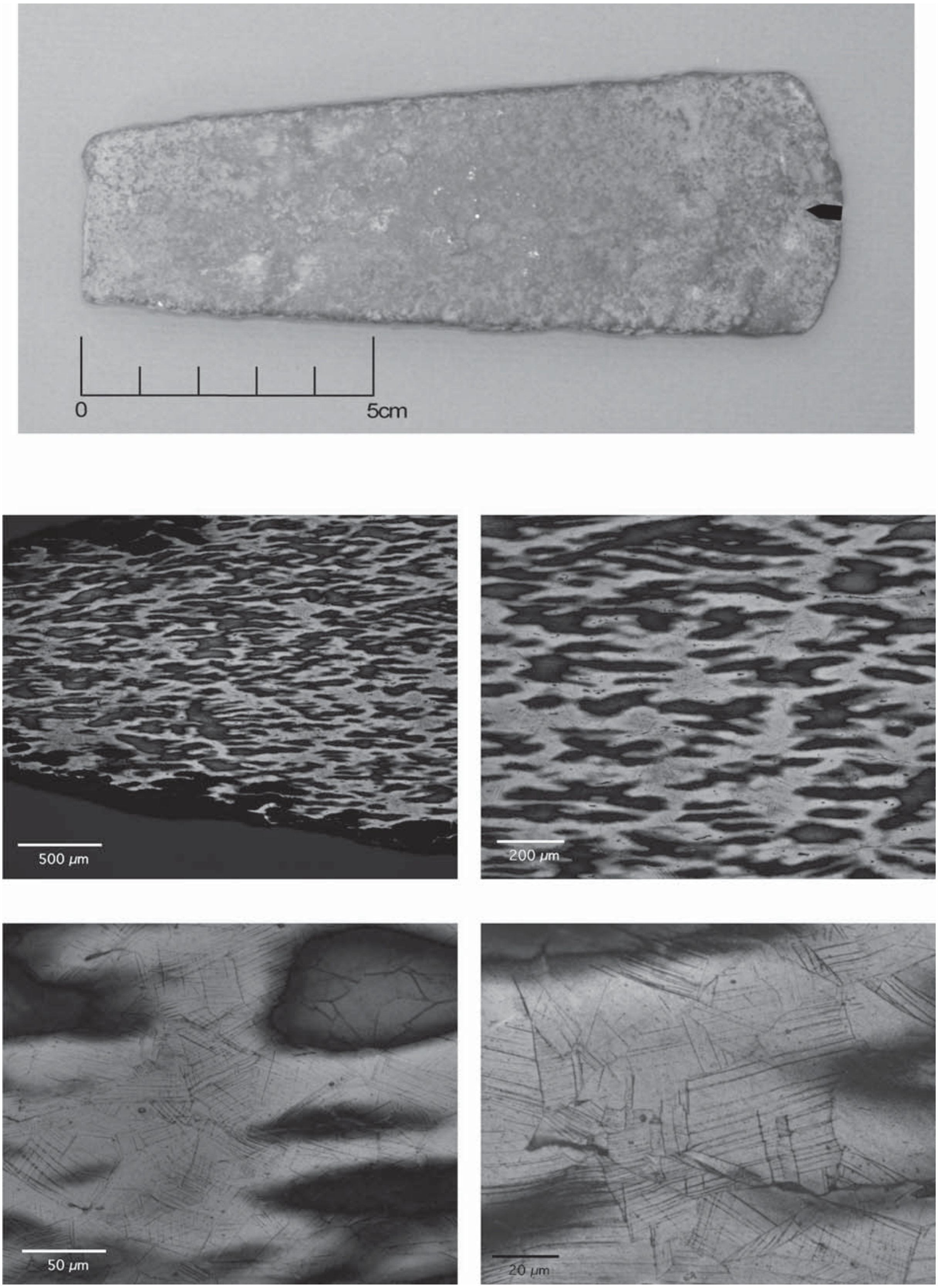


Tab. 64: Sample no. 207.

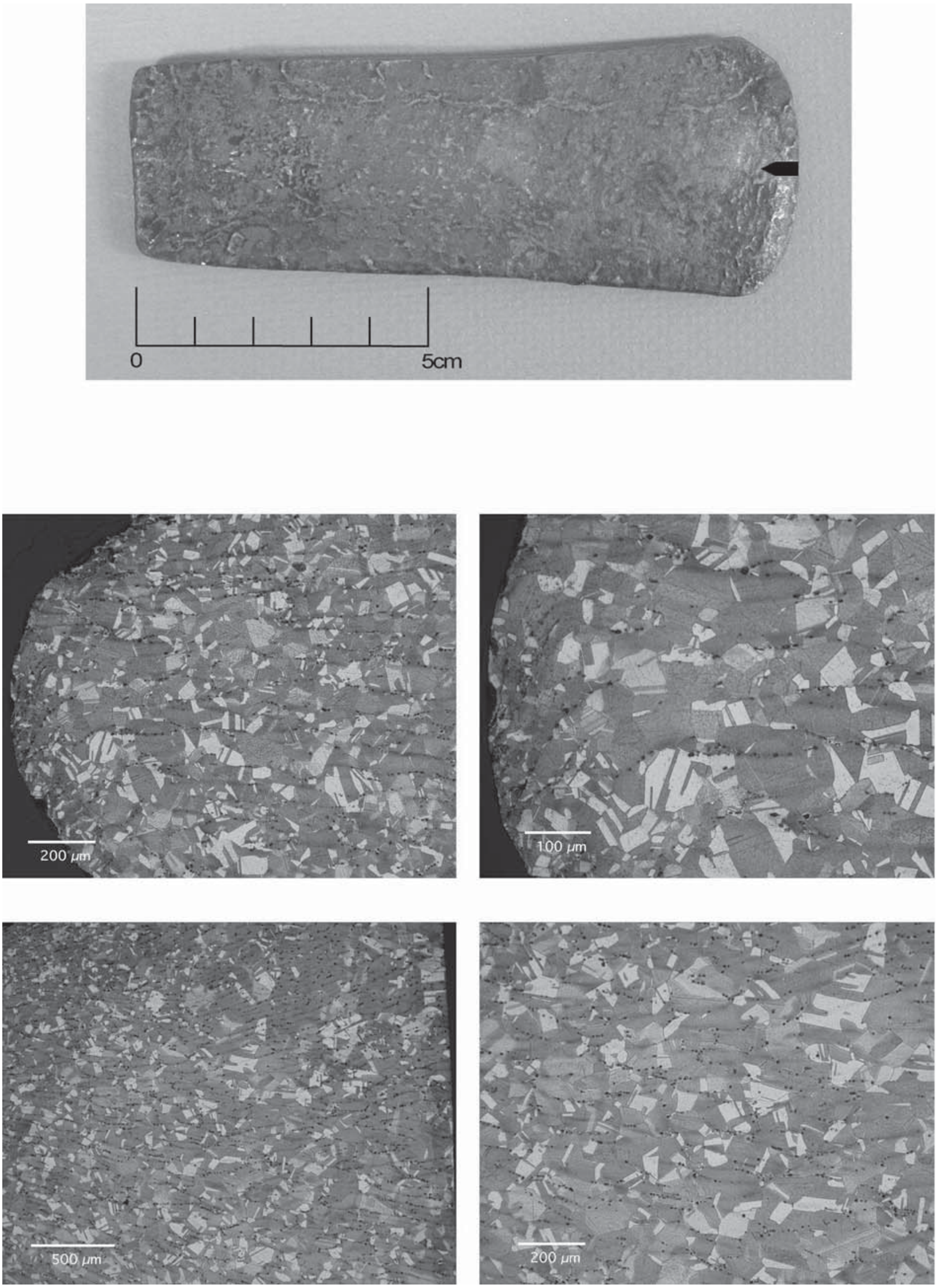
Eneolithic/Copper Age flat axes, horizon 2 (type Vrádište)		
Sample no.	***Origin / context***	***Museum / inv. no.***
56	Vrádište SK settlement find	Bratislava, Slov. Nár. Múz., 7306 Novotná 1970, 15 no. 37 (schmale Kupferbeile)
74	Graz A stray find	Graz, 15209 Mayer 1977, 65 no. 182
154	Prace CZ hoard(?)	Brno, 69521 Říhovský 1992, 66 no. 104 (Gr. VI, Typ Ia, Var. Bb;)



Tab. 65: Sample no. 56.

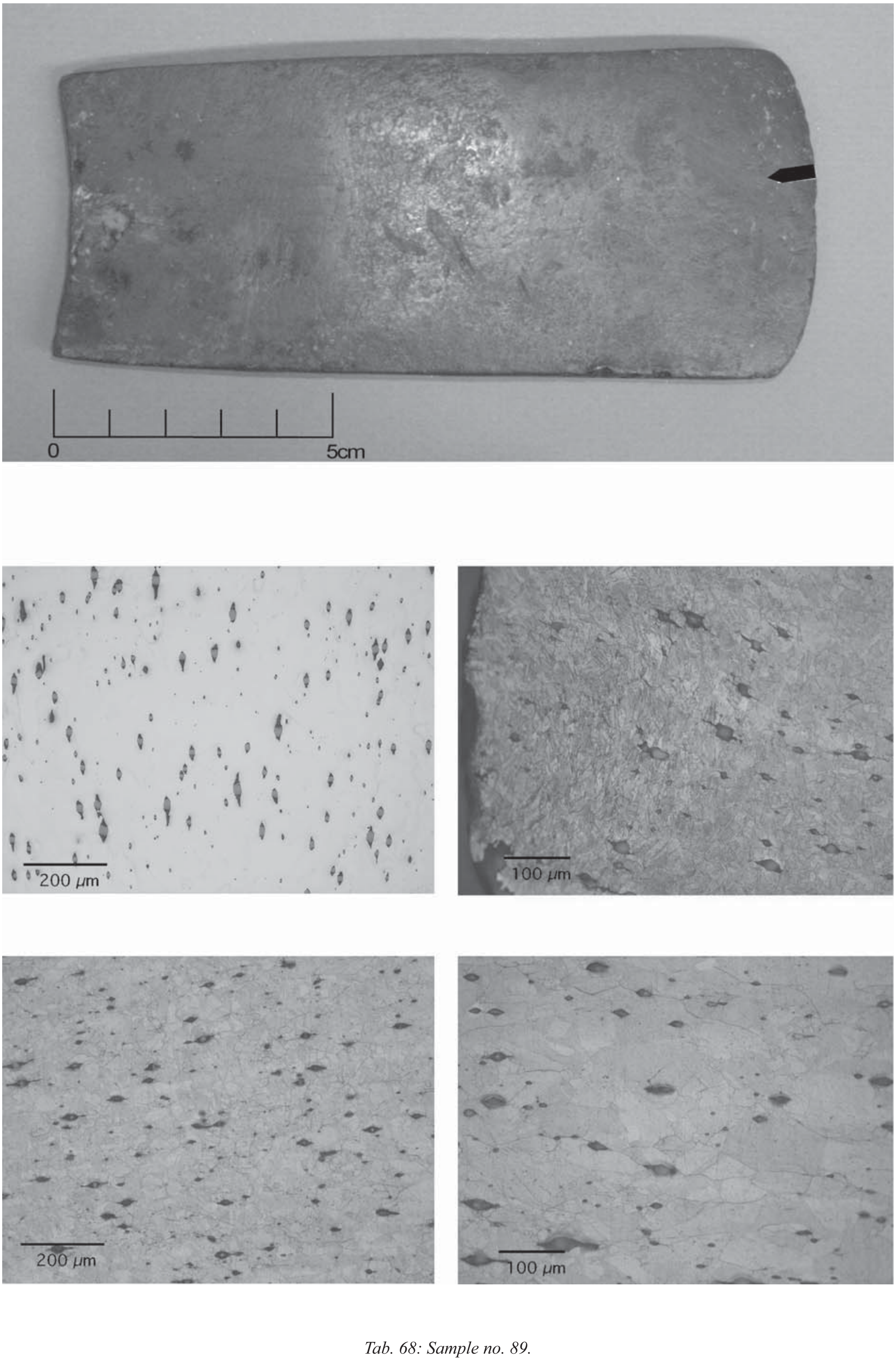


Tab. 66: Sample no. 74.

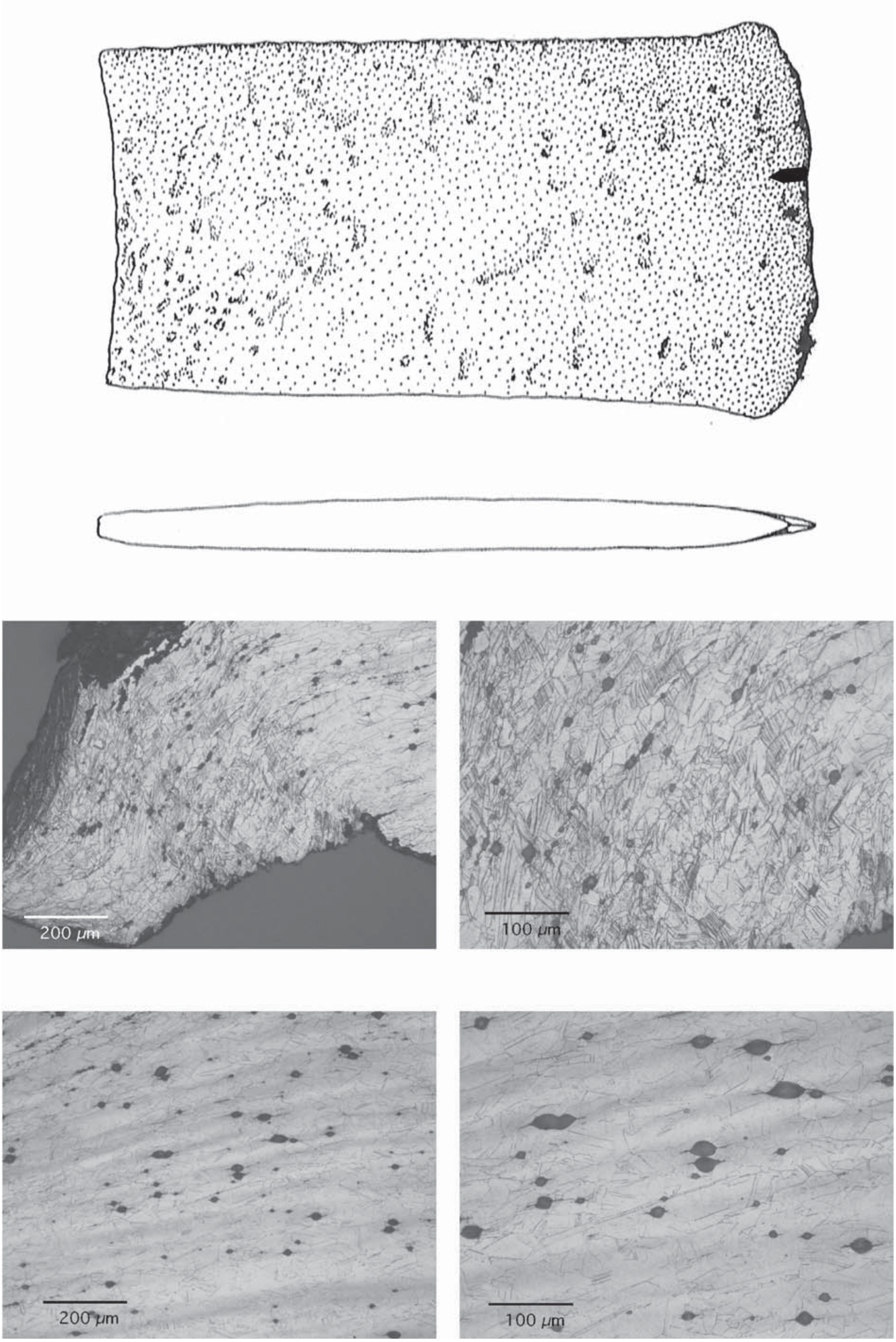


Tab. 67: Sample no. 154.

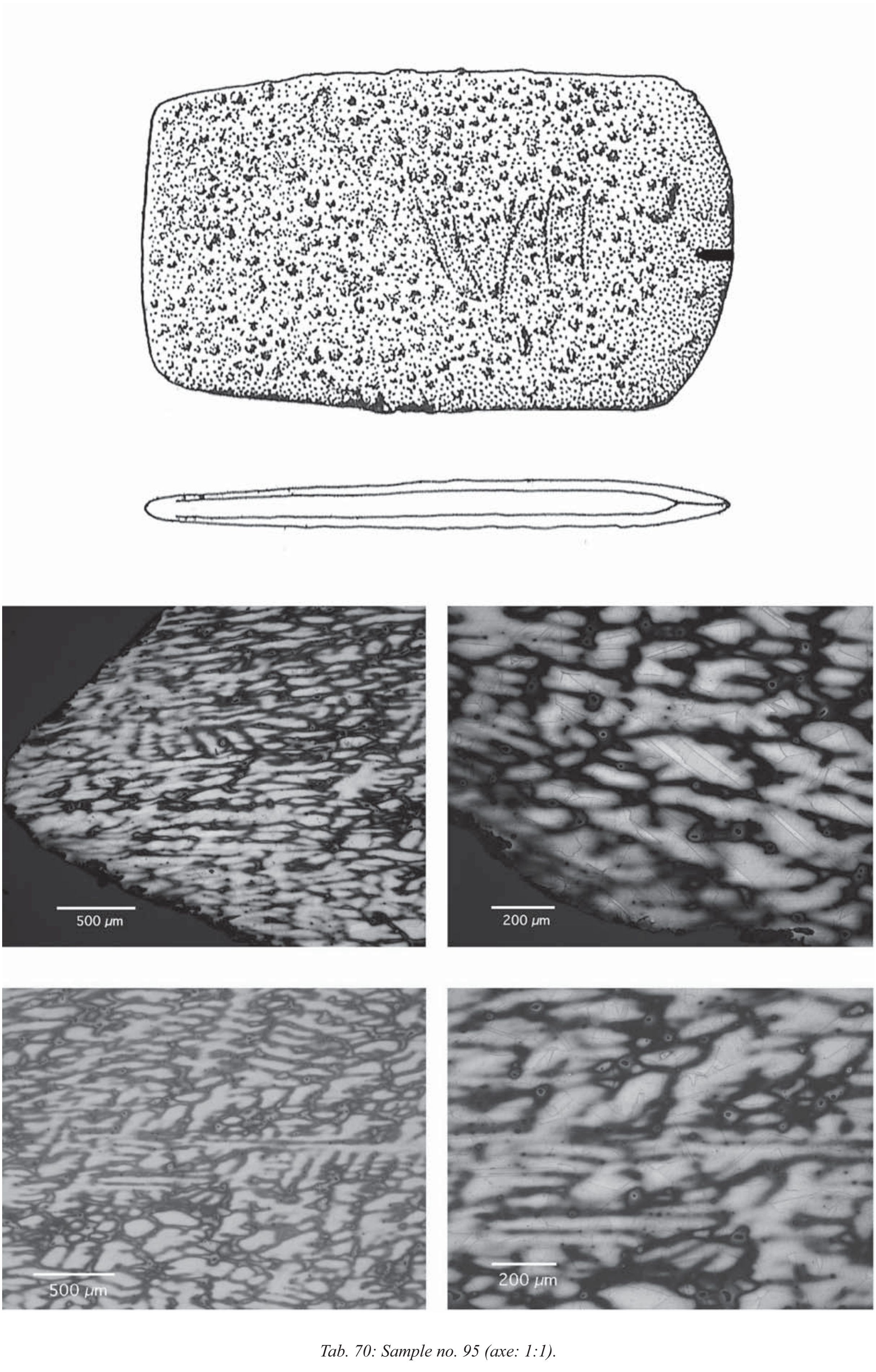
Eneolithic/Copper Age flat axes, horizon 2 (type Vinča)		
Sample no.	***Origin / context***	***Museum / inv. no.***
89	unknown unknown	Wien, Urgesch. Inst., 9000 Mayer 1977, 64 no. 179
90	unknown unknown	Wien, Urgesch. Inst., 9004 Mayer 1977, 64 no. 177
95	unknown unknown	Wien, Urgesch. Inst., 9002 Mayer 1977, 64 no. 180
97	unknown unknown	Wien, Urgesch. Inst., 9005 Mayer 1977, 64 no. 175
99	Moravia	Wien, Urgesch. Inst., 9008
112	unknown unknown	Wien, Urgesch. Inst., 9003 Mayer 1977, 64 no. 174



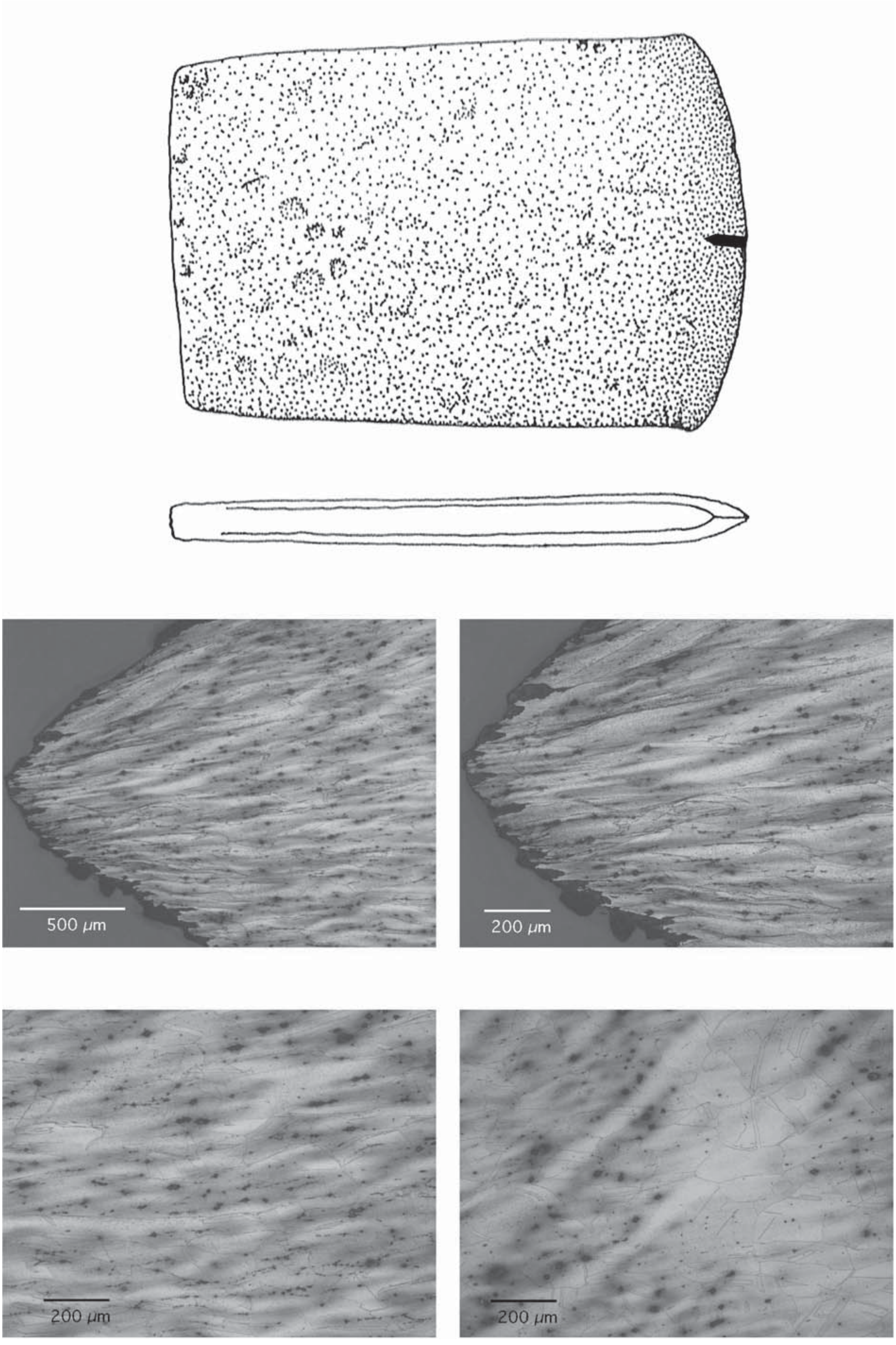
Tab. 68: Sample no. 89.



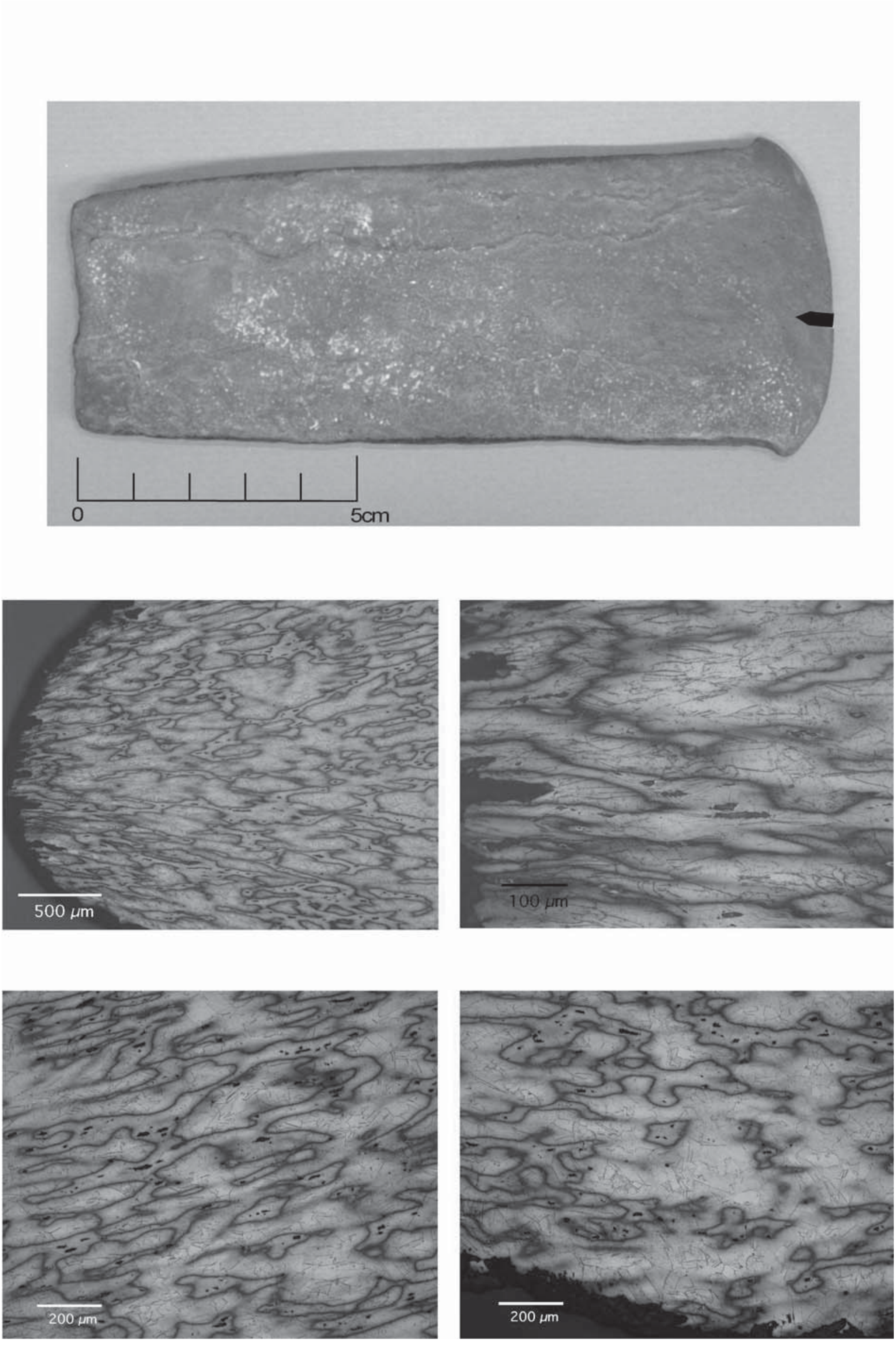
Tab. 69: Sample no. 90 (axe: 1:1).



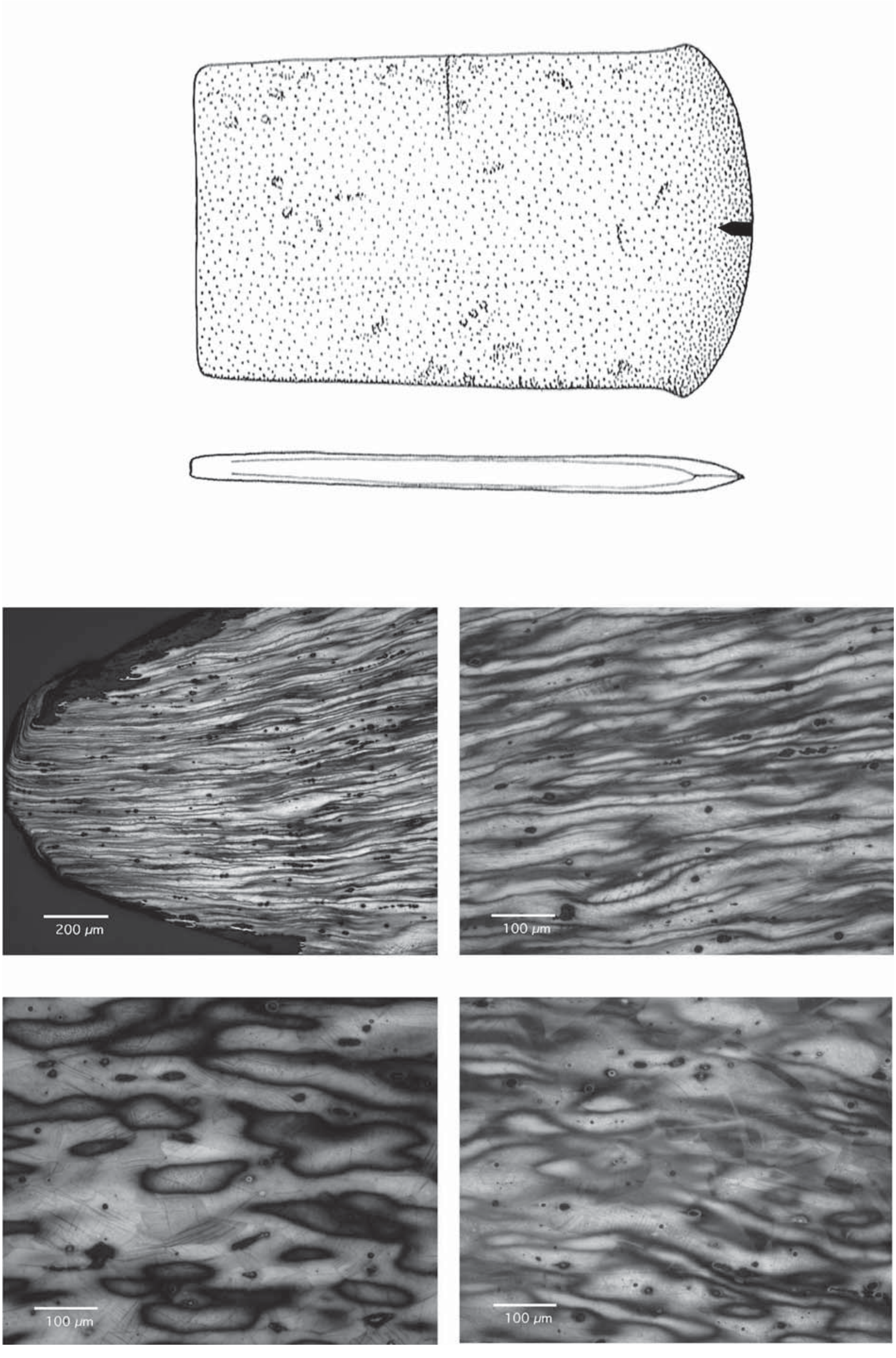
Tab. 70: Sample no. 95 (axe: 1:1).



Tab. 71: Sample no. 97 (axe: 1:1).



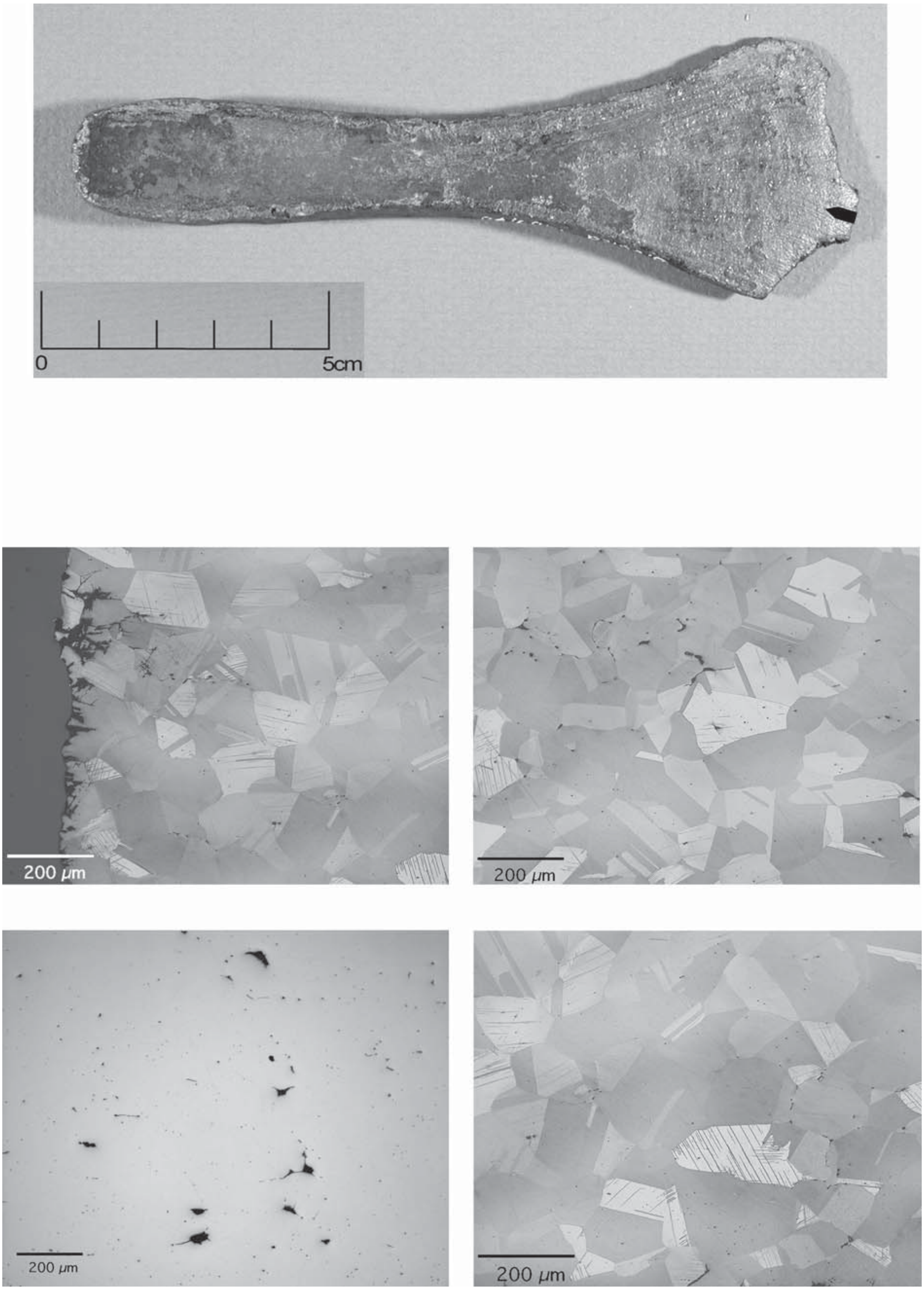
Tab. 72: Sample no. 99.



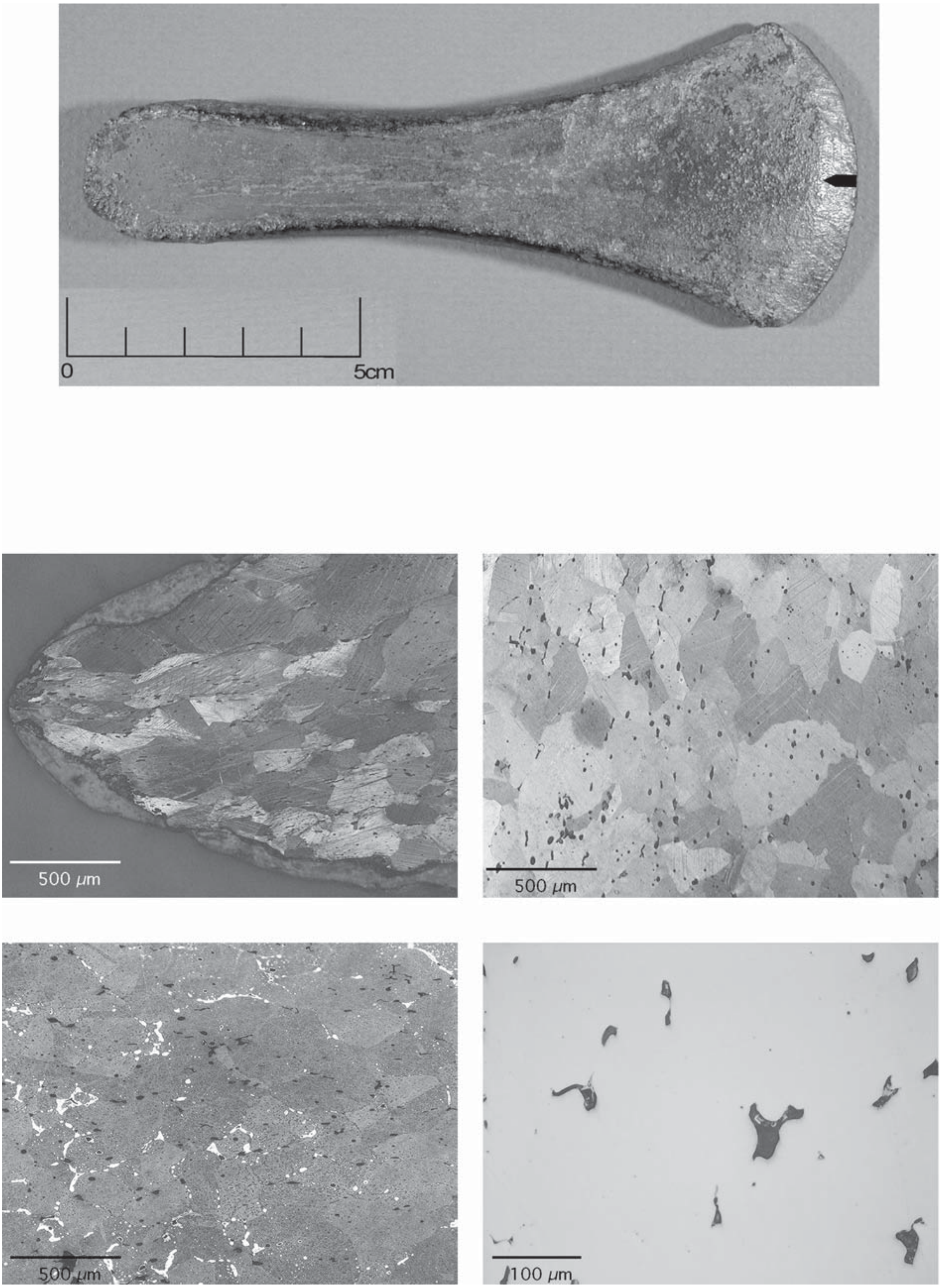
Tab. 73: Sample no. 112 (axe: 1:1).

Bronze Age horizon 1 (EBA Saxon type flanged axes etc.)		
Sample no.	***Origin / context***	***Museum / inv. no.***
1	Bad Sulza D stray find	Weimar, 1509/70 SAM / FMZM: 32217 / 0292
2	Mittelhausen D hoard	Weimar, 1640 SAM / FMZM: 32173 / 0248
7	unknown unknown	Zeitz, III/64-113b
8	unknown unknown	Zeitz, III/64-113a
9	Meineweh D hoard(?)	Zeitz, III/78/32
11	Meineweh D hoard(?)	Zeitz, III/55/6 SAM / FMZM: 34227 / 2305
17	Eilenstedt D stray find	Halberstadt, 3822 SAM / FMZM: 34690 / 2768
18	Rohrsheim D unknown	Halberstadt, 2689/493 SAM / FMZM: 34696 / 2774
20	Hordorf (Wulferstedt) D	Halberstadt, 1221 SAM / FMZM: 34686 / 2764
21	Groß Quenstedt D stray find	Halberstadt, 2156 SAM / FMZM: 34670 / 2748
22	Ottleben D unknown	Halberstadt, 2442 SAM / FMZM: 34692 / 2770
26	Schwaan D depot / river(?)	Rostock, 35/1 SAM / FMZM: 33233 / 1311
27	Schwaan D depot / river(?)	Rostock, 1906 VI,3 SAM / FMZM: 33181 / 1259
28	Schwaan D depot / river(?)	Rostock, 27/4 SAM / FMZM: 33096 / 1174
34	Carsdorf D hoard	Leipzig, V 2387,29 Billig 1958, 82–90
51	Bernolákovo SK grave	Bratislava, Slov. Nár. Múz., 10799 Novotná 1970, 36 no. 201 (Randleistenbeile mit flachem Nacken und bogenförmiger Schneide)
54	Dunajská Streda SK hoard	Bratislava, Slov. Nár. Múz., 2183 Novotná 1970, 36 no. 195 (Randleistenbeile mit flachem Nacken und bogenförmiger Schneide)
69	unknown unknown	Bratislava, Mest. Múz., 1410 / 593 Novotná 1970, 34 no. 170 (Randleistenbeile mit spitzem Nacken)
75	Murau A stray find	Graz, 14904 Mayer 1977, 67 no. 210 (type Niederosterwitz)
114	Veľký Grob SK grave	Nitra, AÚSAV, (grave) 8/52 Novotná 1970, 33 no. 168 (Randleistenbeile mit spitzem Nacken)
119	Slanská Hora CZ	Olomouc, A 69480
124	Olšany CZ hoard	Olomouc, 2295 Říhovský 1992, 85 no. 184 (Gr. IV, Typ 5c, Var. Dab)
125	Slatinky CZ stray find	Olomouc, 5255 / A 68257 Říhovský 1992, 84 no. 175 (Gr. IV, Typ 4b, Var. D)
126	Olomouc-Slavonin CZ grave	Olomouc, Slavonin grave 46
127	Čechyně CZ stray find	Brno, 16293 Říhovský 1992, 82 no. 167 (Gr. III, Typ 3c, Var. Aab)
131	Dobročkovice CZ hoard	Brno, 53625 Říhovský 1992, 115 no. 272 (Gr. III, Typ Ib, Var. ?)
132	Dobročkovice CZ hoard	Brno, 53622 Říhovský 1992, 86 no. 190 (Gr. IV, Typ 5c, Var. Ea)
133	Dobročkovice CZ hoard	Brno, 53621 Říhovský 1992, 85 no. 181 (Gr. IV, Typ 5c, Var. Dab)
135	Dobročkovice CZ hoard	Brno, 53627 Říhovský 1992, 84 no. 178 (Gr. IV, Typ 5c, Var. Bab)

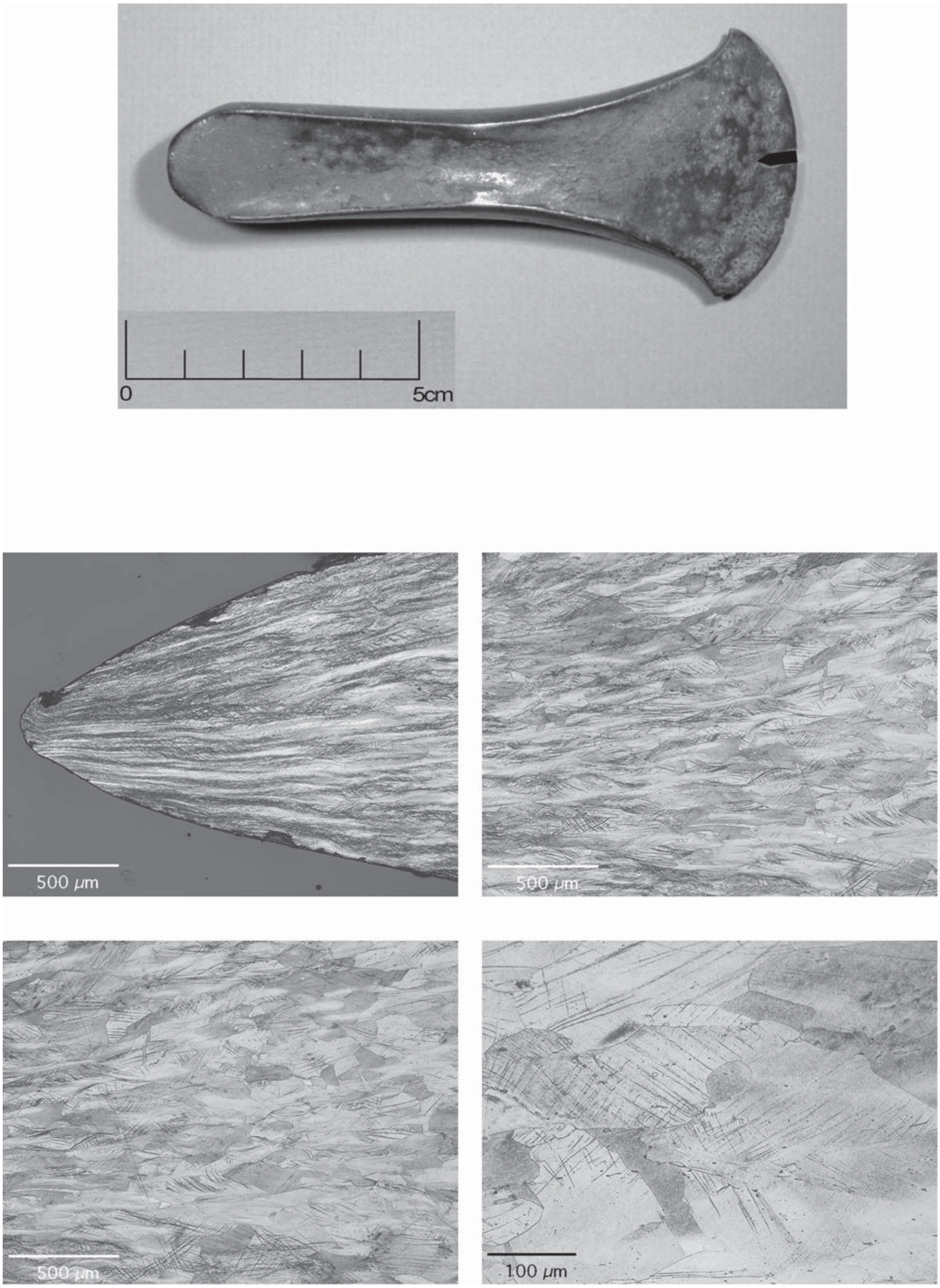
Bronze Age horizon 1 (EBA Saxon type flanged axes etc.)		
Sample no.	***Origin / context***	***Museum / inv. no.***
145	Otaslavice CZ stray find	Brno, 76103 Říhovský 1992, 86 no. 194 (Gr. IV, Typ 5c, Var. Ea)
146	Křižanovice CZ settlement	Brno, 54605 Říhovský 1992, 107 no. 235 (fragment)
151	Kyjov CZ grave	Brno, 69389 Říhovský 1992, 85 no. 183 (Gr. IV, Typ 5c, Var. Dab)
152	Borotice CZ hoard	Brno, 69312 Říhovský 1992, 105 no. 232 (Gr. XII, Typ 5c, Var. Da)
158	Dobročkovice CZ hoard	Brno, 53624 Říhovský 1992, 88 no. 203 (Gr. IV)
159	Viničné Šumice stray find	Brno, 86942 Říhovský 1992, 86 no. 188 (Gr. IV, Typ 5c, Var. Dab)
162	Dobročkovice CZ hoard	Brno, 53619 Říhovský 1992, 105 no. 233 (Gr. XII, Typ 5c, Var. Da)
163	Dobročkovice CZ hoard	Brno, 53620 Říhovský 1992, 86 no. 189 (Gr. IV, Typ 5c, Var. Ea)
166	Moravský Krumlov CZ grave(?)	Brno, 436 Říhovský 1992, 88 no. 204 (Gr. IV)
167	Hradce CZ hoard	České Budějovice, J I 144 4 Stein 1979, 100 no. 228 (type Langquaid)
168	Hradce CZ hoard	České Budějovice, J I 2 6 Stein 1979, 100 no. 228 (type Langquaid)
169	Hradce CZ hoard	České Budějovice, J I 1 5 Stein 1979, 100 no. 228 (type Langquaid)
171	Plavnice / Kamenný Újezd CZ hoard	České Budějovice, AO 604 Stein 1979, 101 no. 232 (type Langquaid I)
172	Plavnice / Kamenný Újezd CZ hoard	České Budějovice, AO 605 Stein 1979, 101 no. 232 (type Neyruz)
173	Plavnice / Kamenný Újezd CZ hoard	České Budějovice, AO 607 Stein 1979, 101 no. 232 (Saxon type)
174	Plavnice / Kamenný Újezd CZ hoard	České Budějovice, AO 606 Stein 1979, 101 no. 232 (Saxon type)



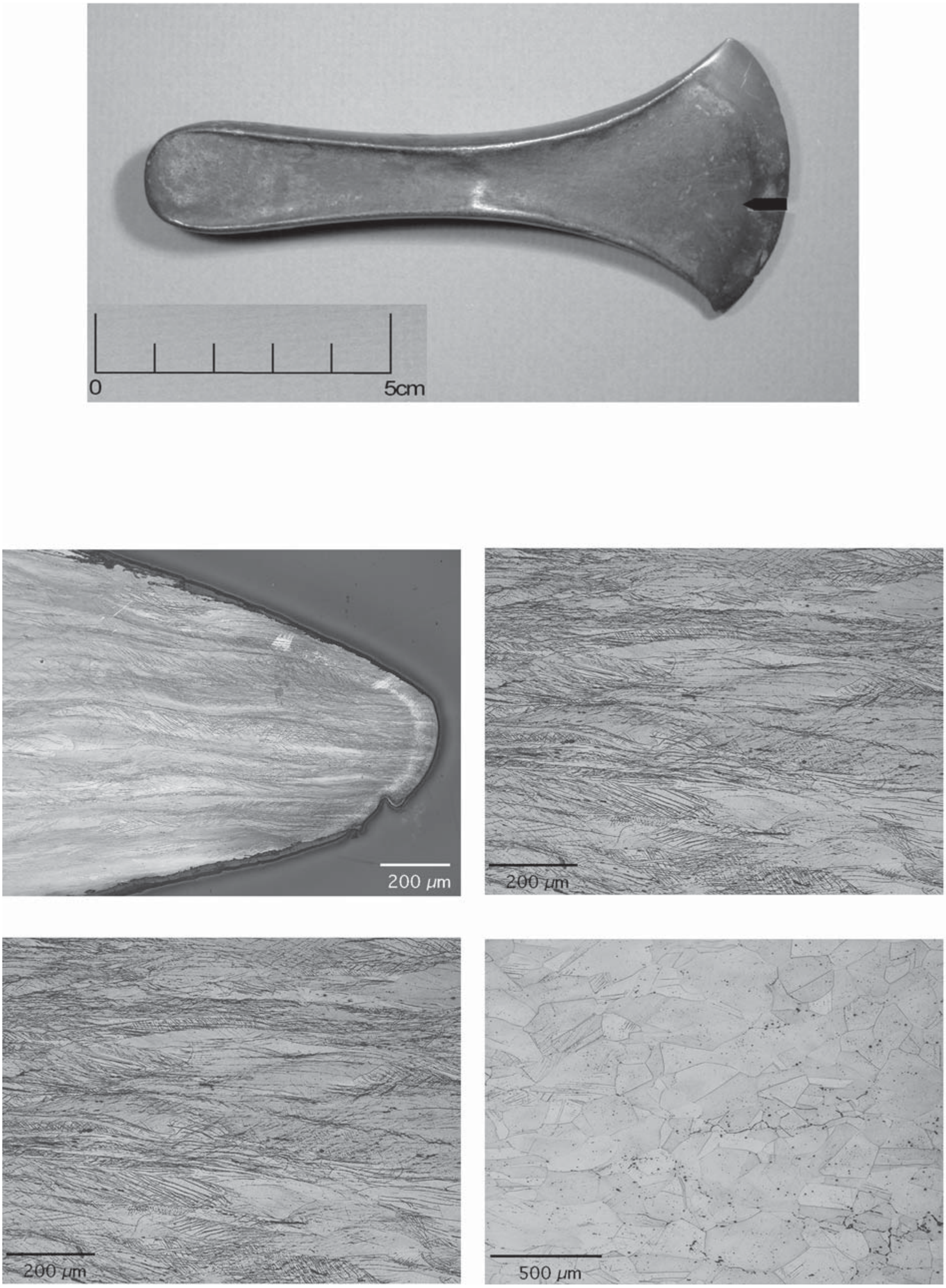
Tab. 74: Sample no. 1.



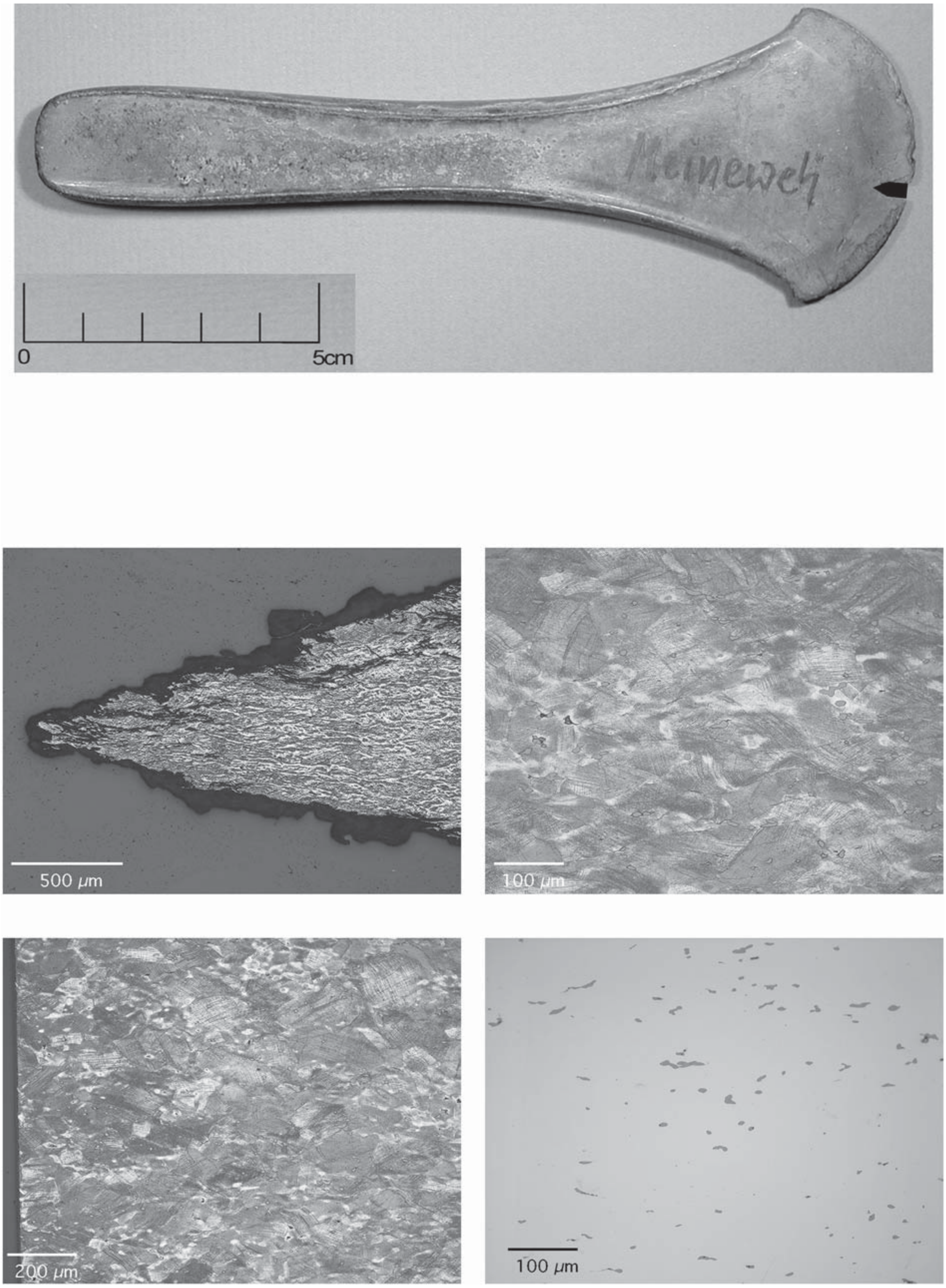
Tab. 75: Sample no. 2.



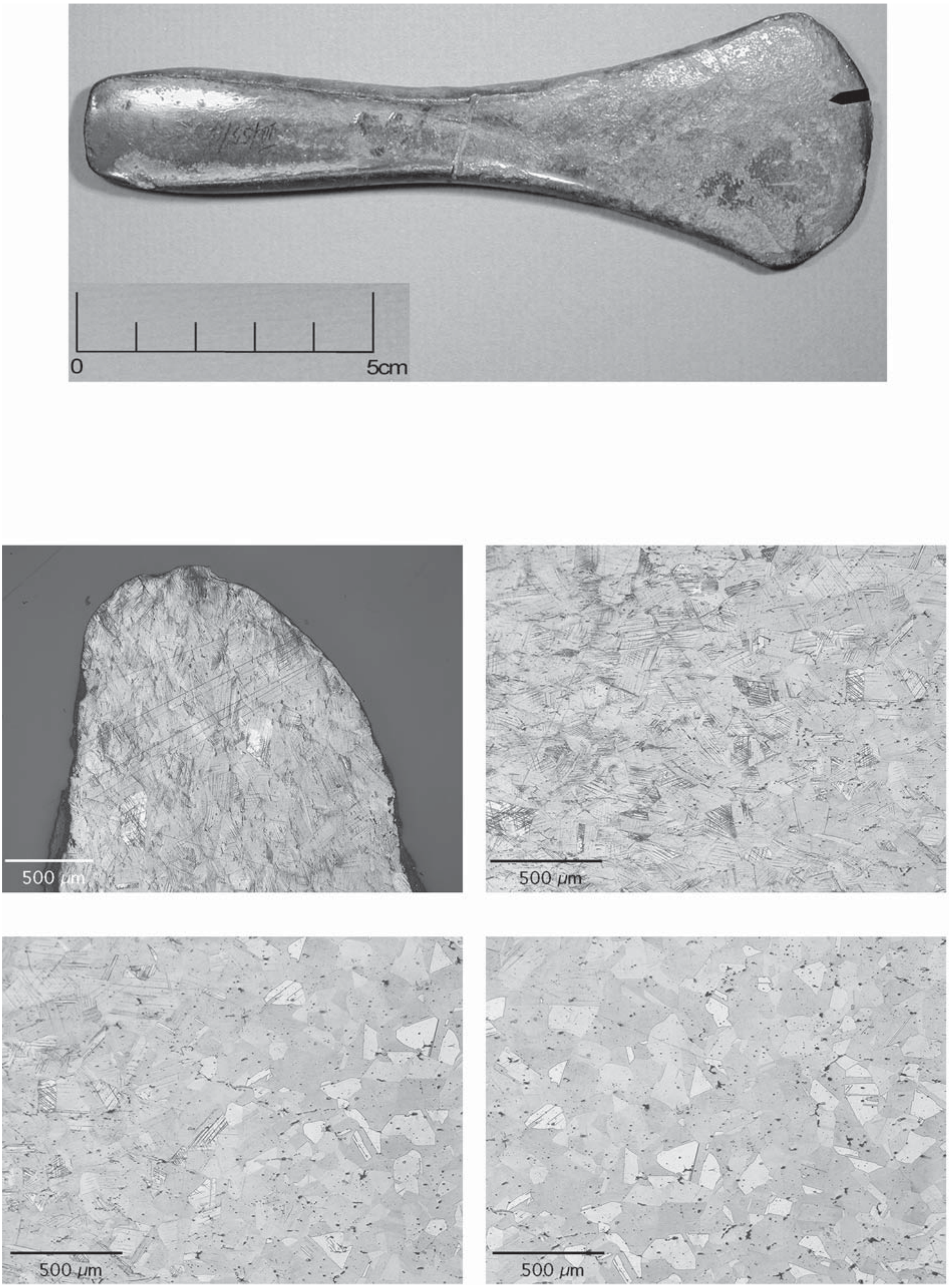
Tab. 76: Sample no. 7.



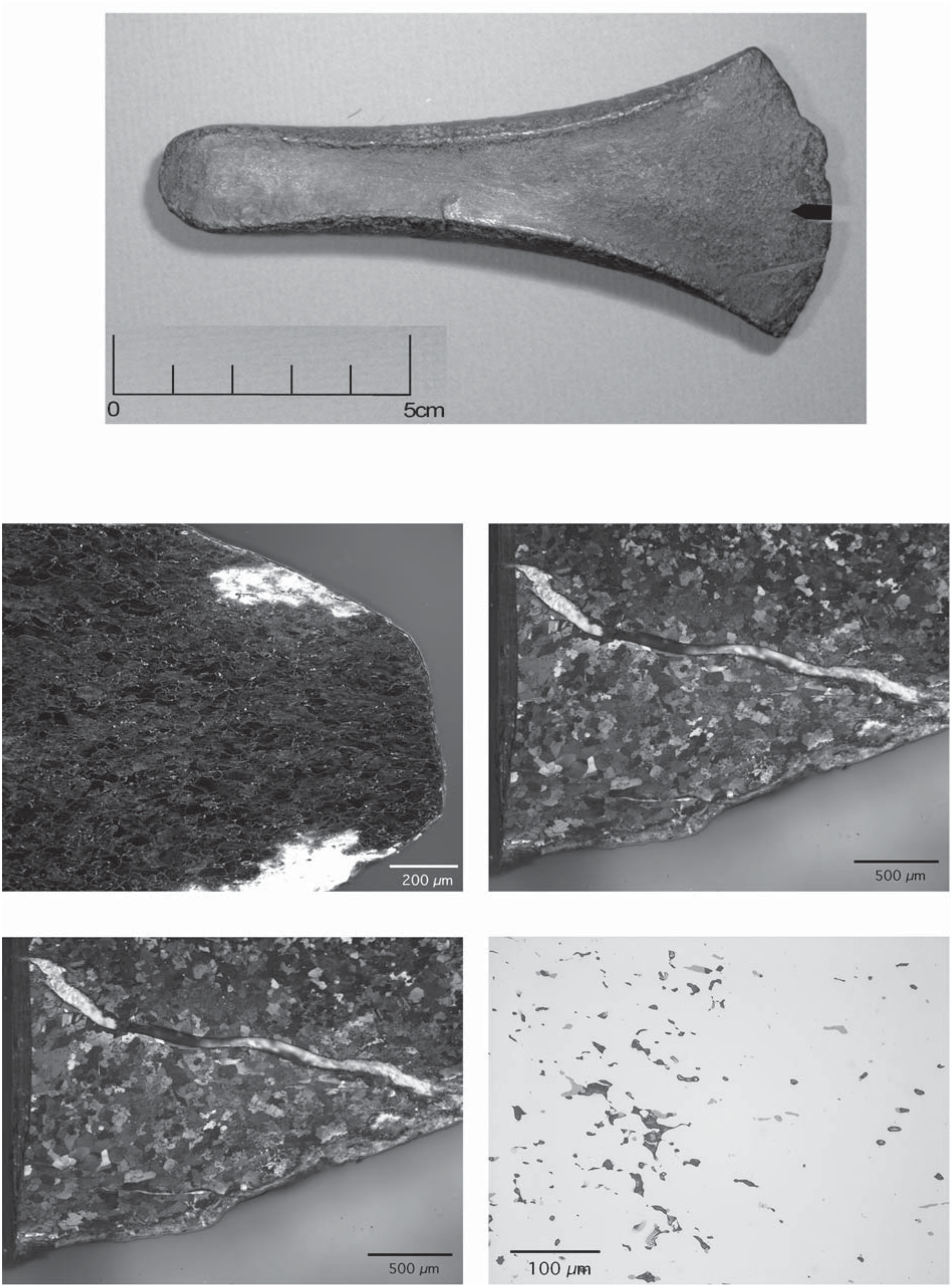
Tab. 77: Sample no. 8.



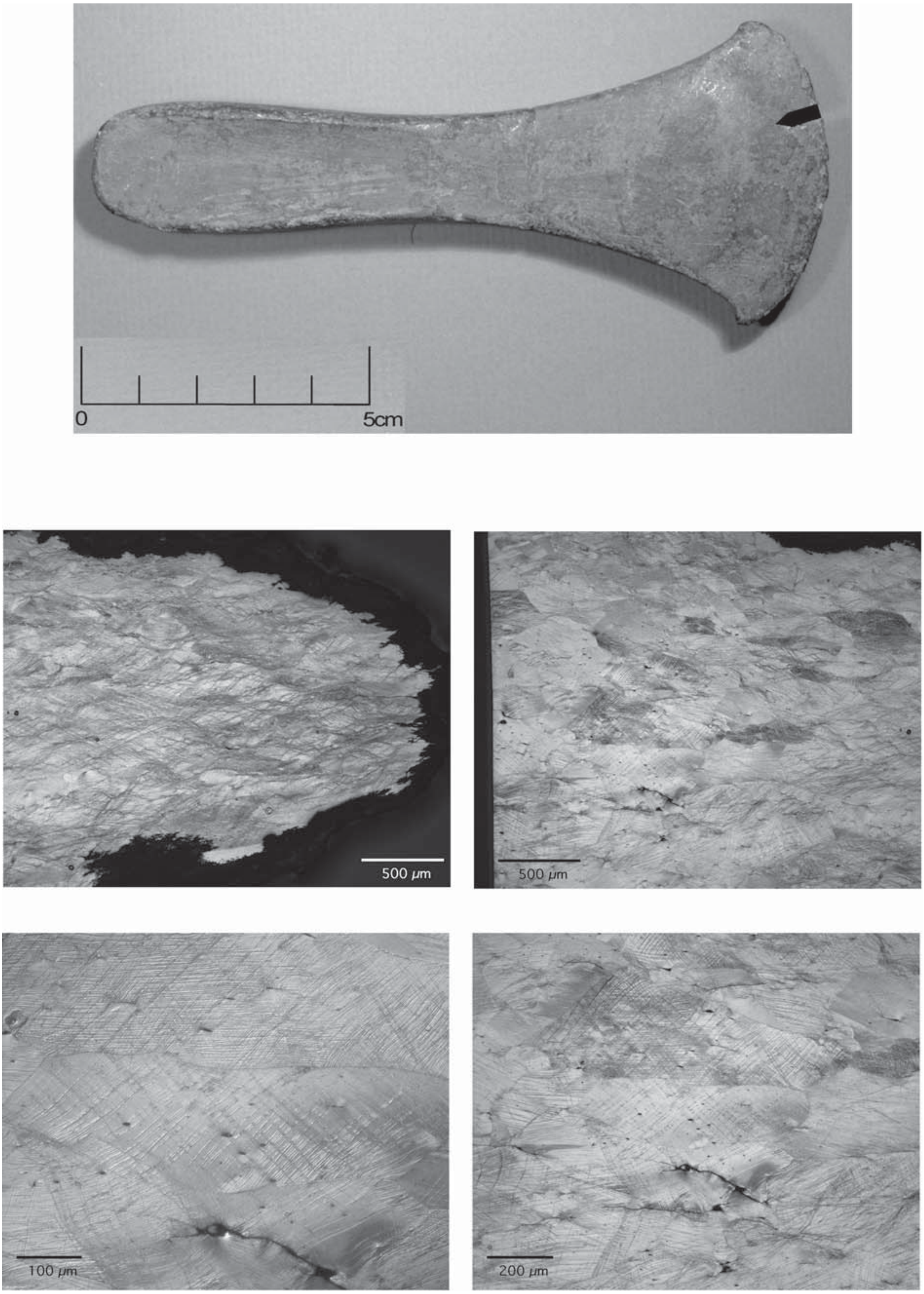
Tab. 78: Sample no. 9.



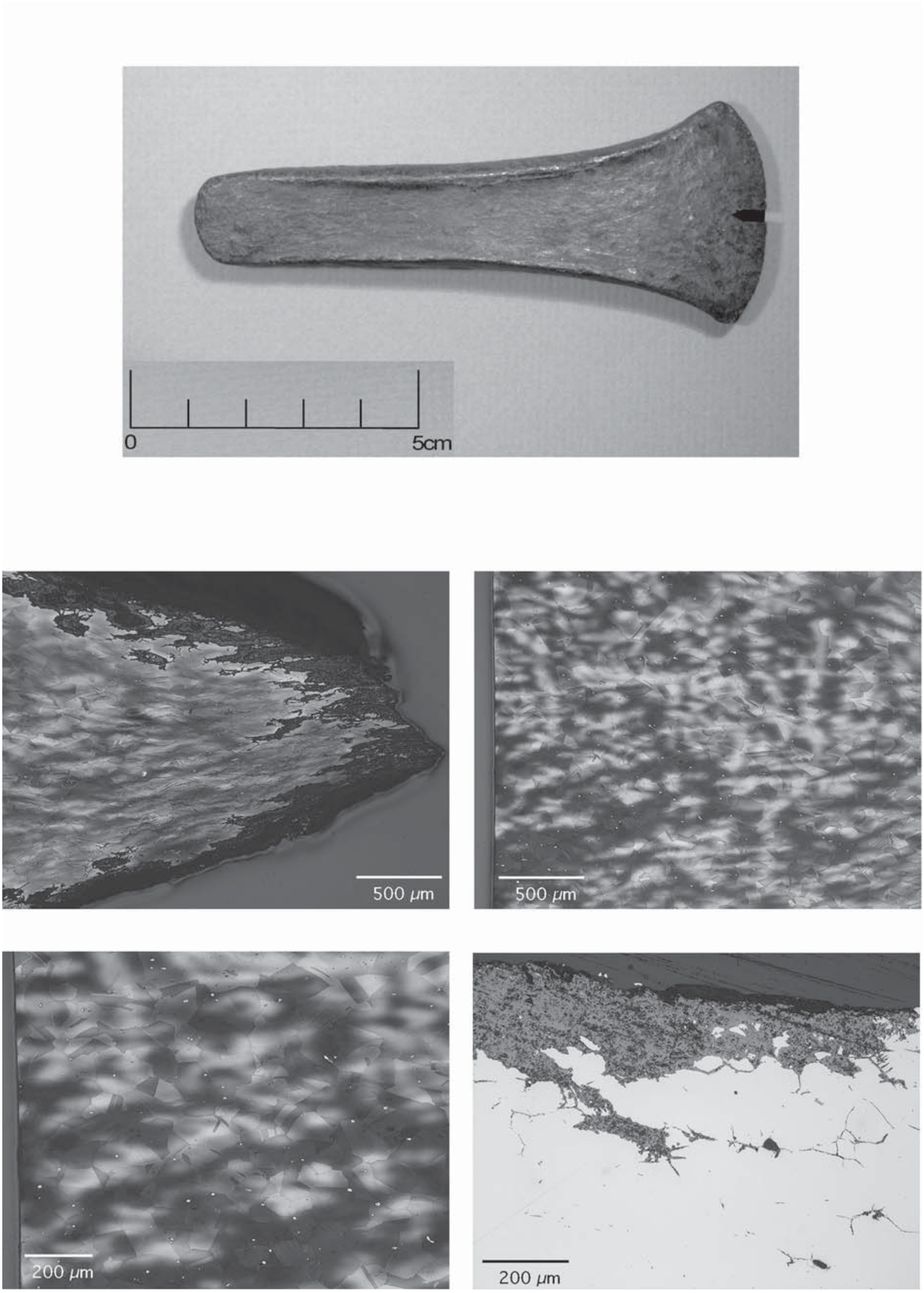
Tab. 79: Sample no. 11.



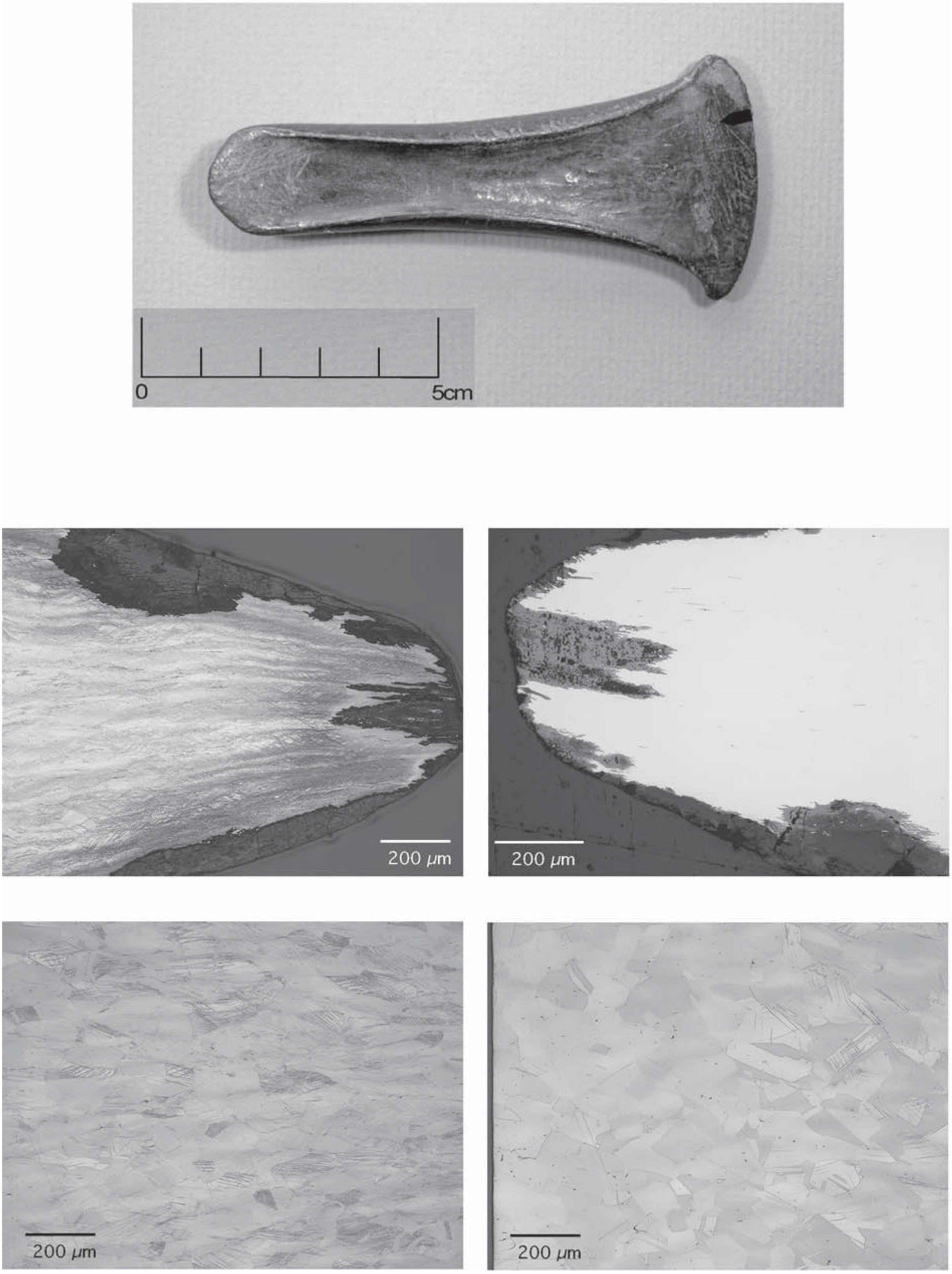
Tab. 80: Sample no. 17.



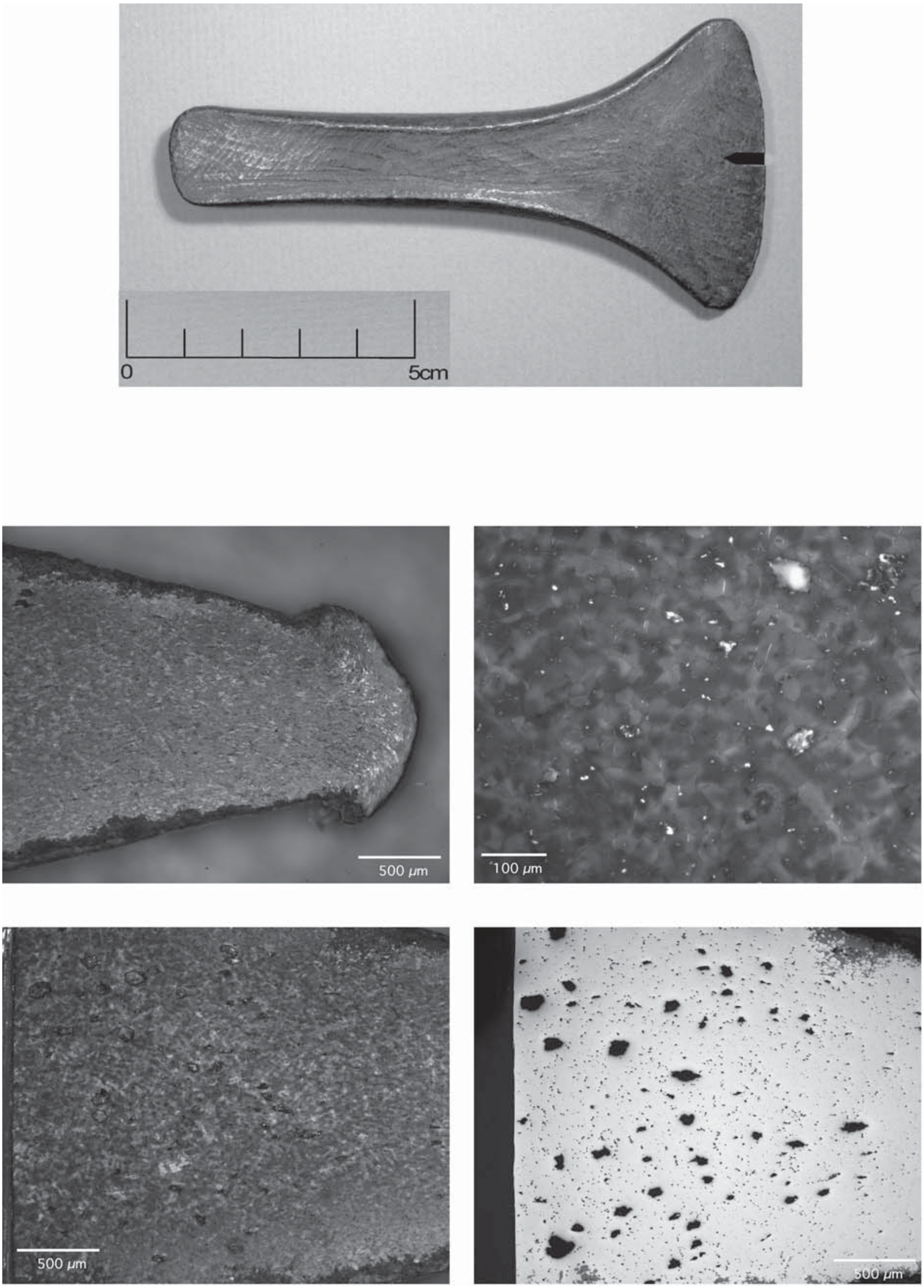
Tab. 81: Sample no. 18.



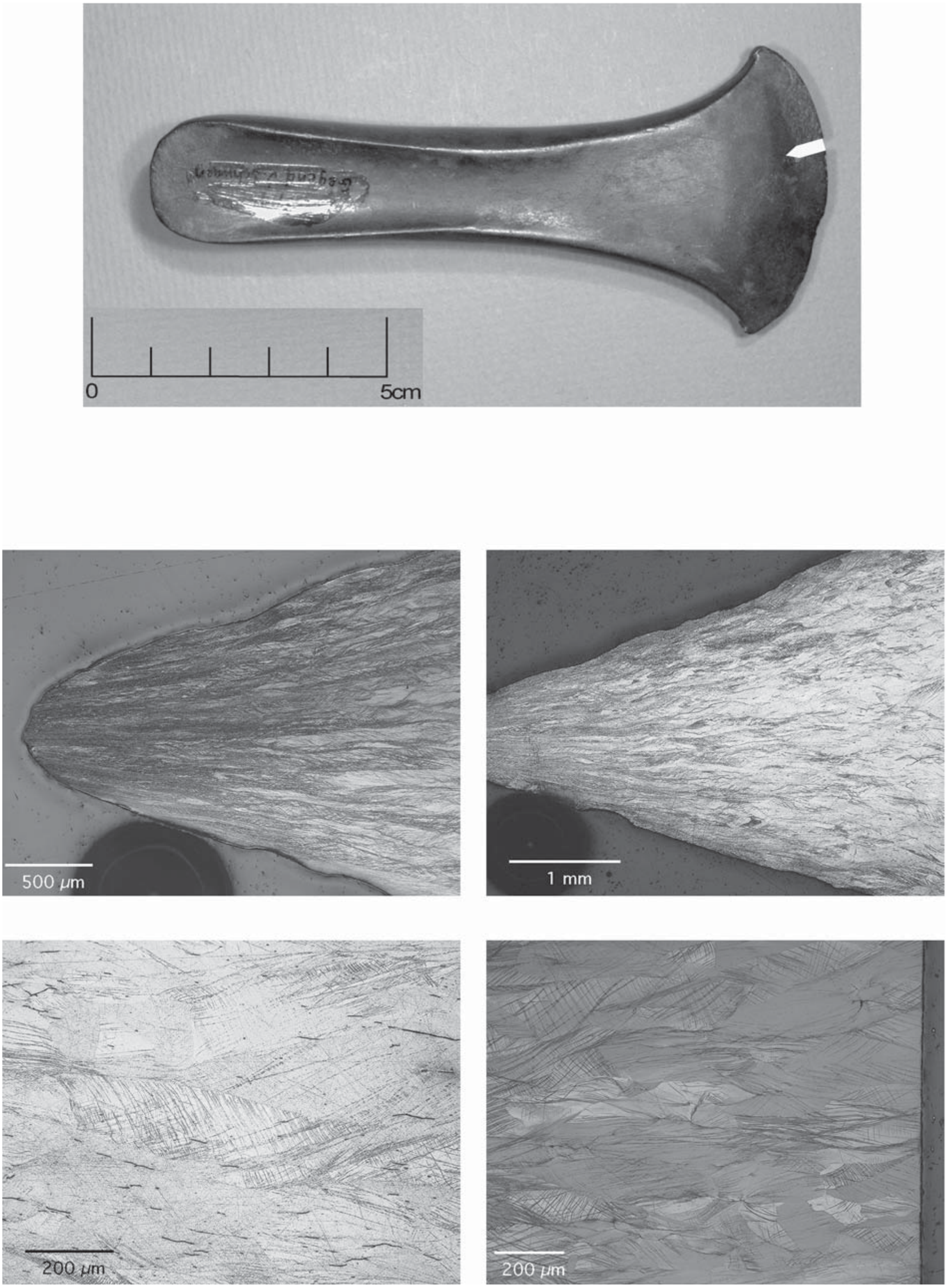
Tab. 82: Sample no. 20.



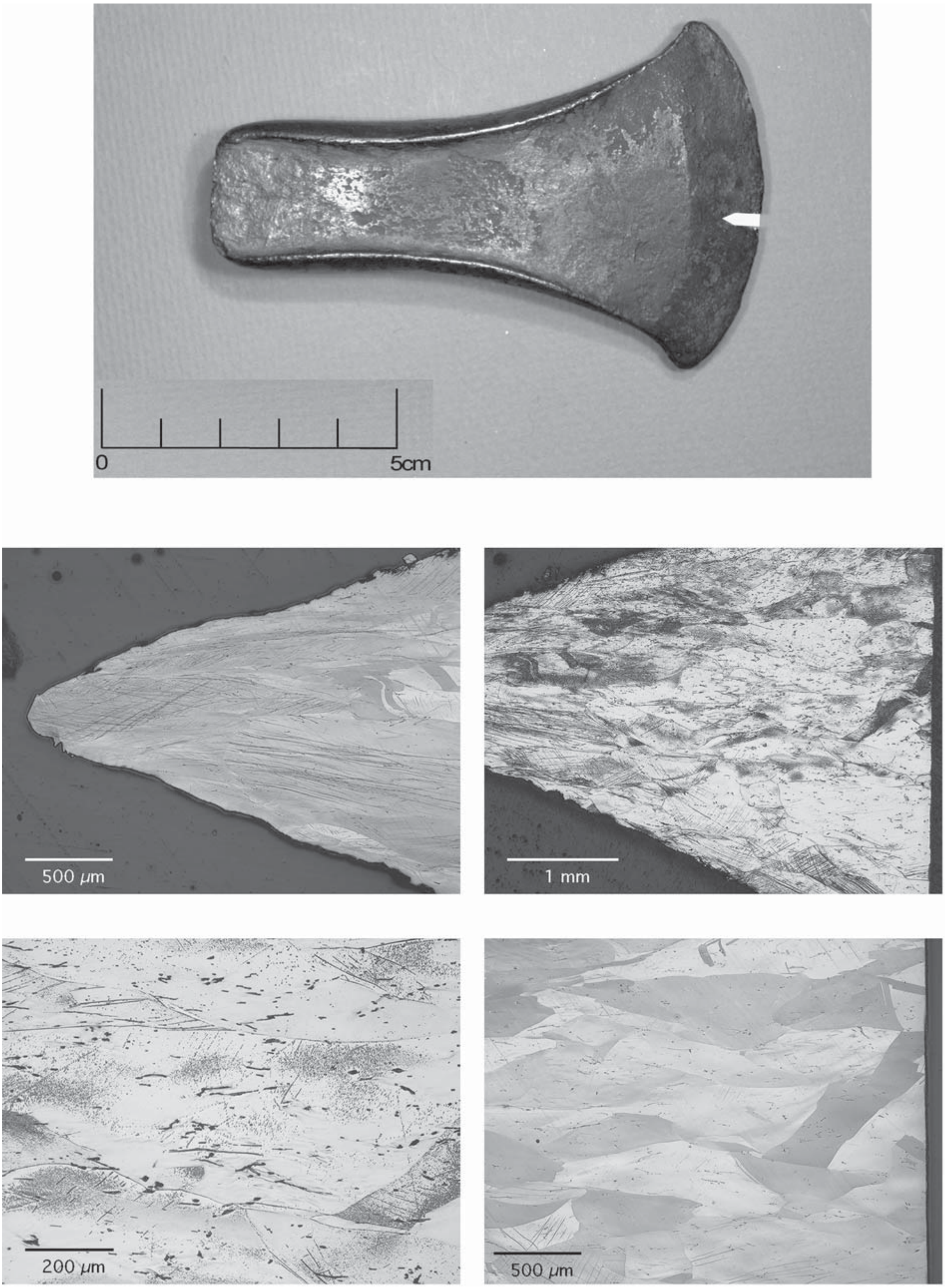
Tab. 83: Sample no. 21.



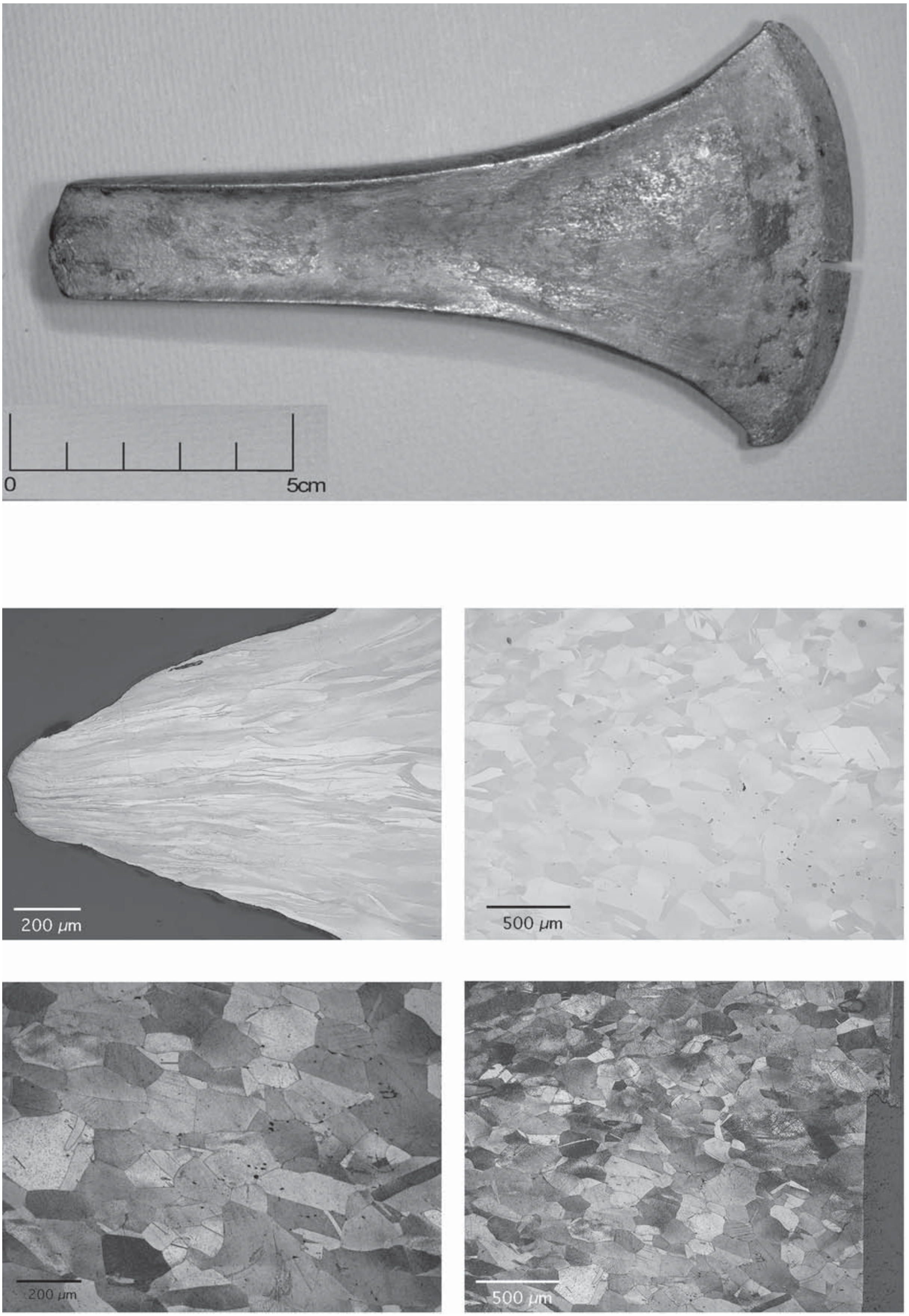
Tab. 84: Sample no. 22.



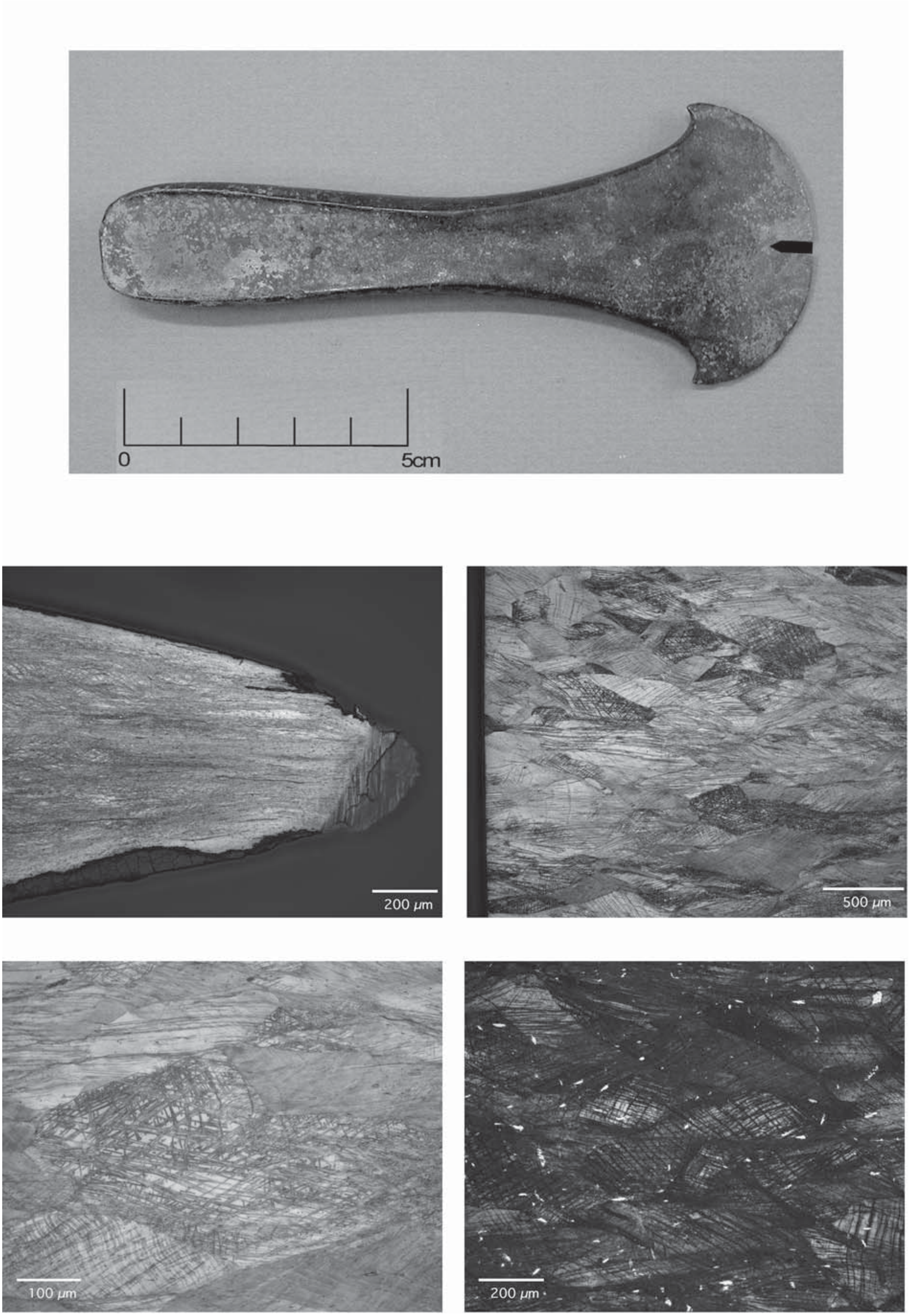
Tab. 85: Sample no. 26.



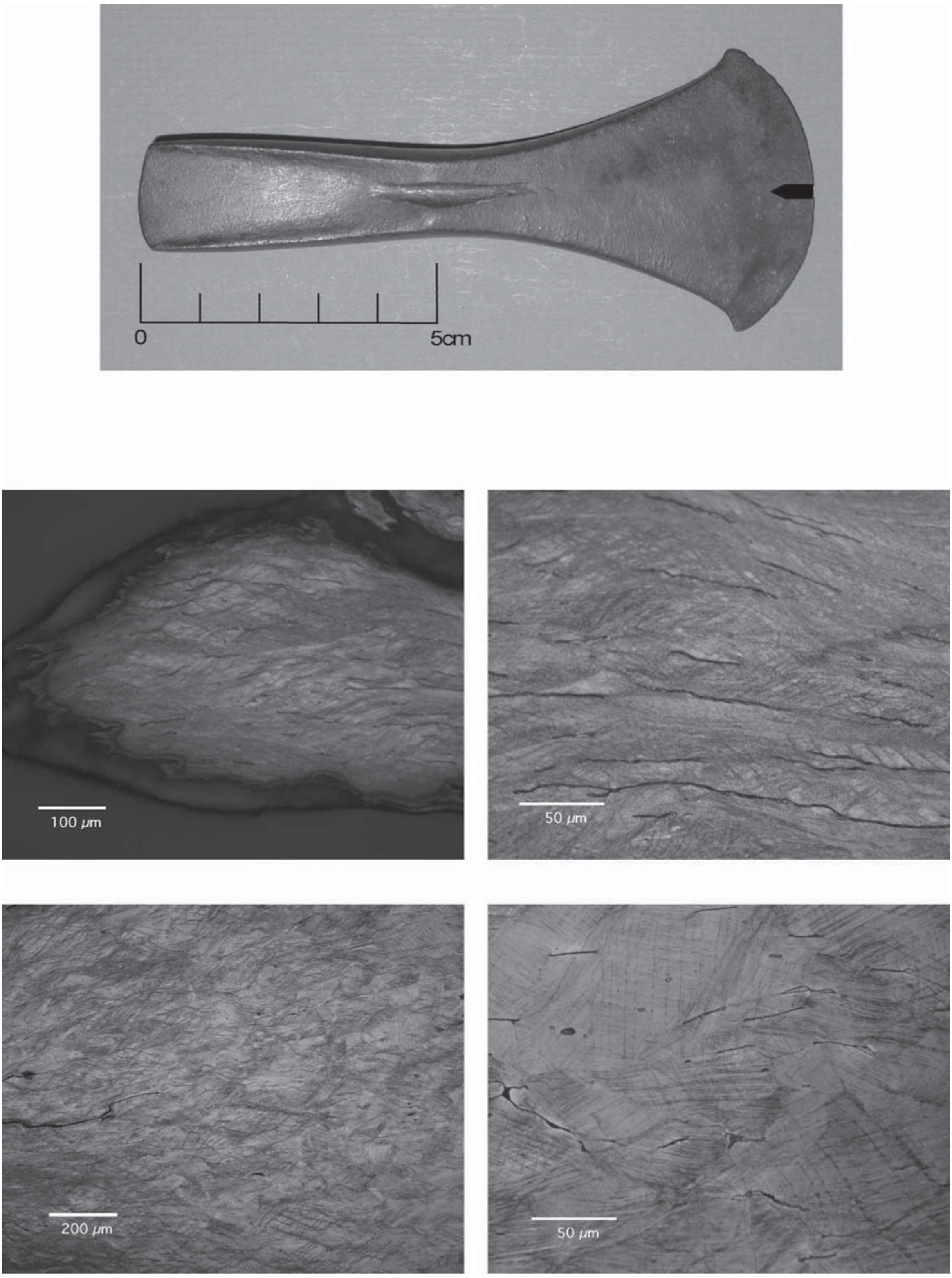
Tab. 86: Sample no. 27.



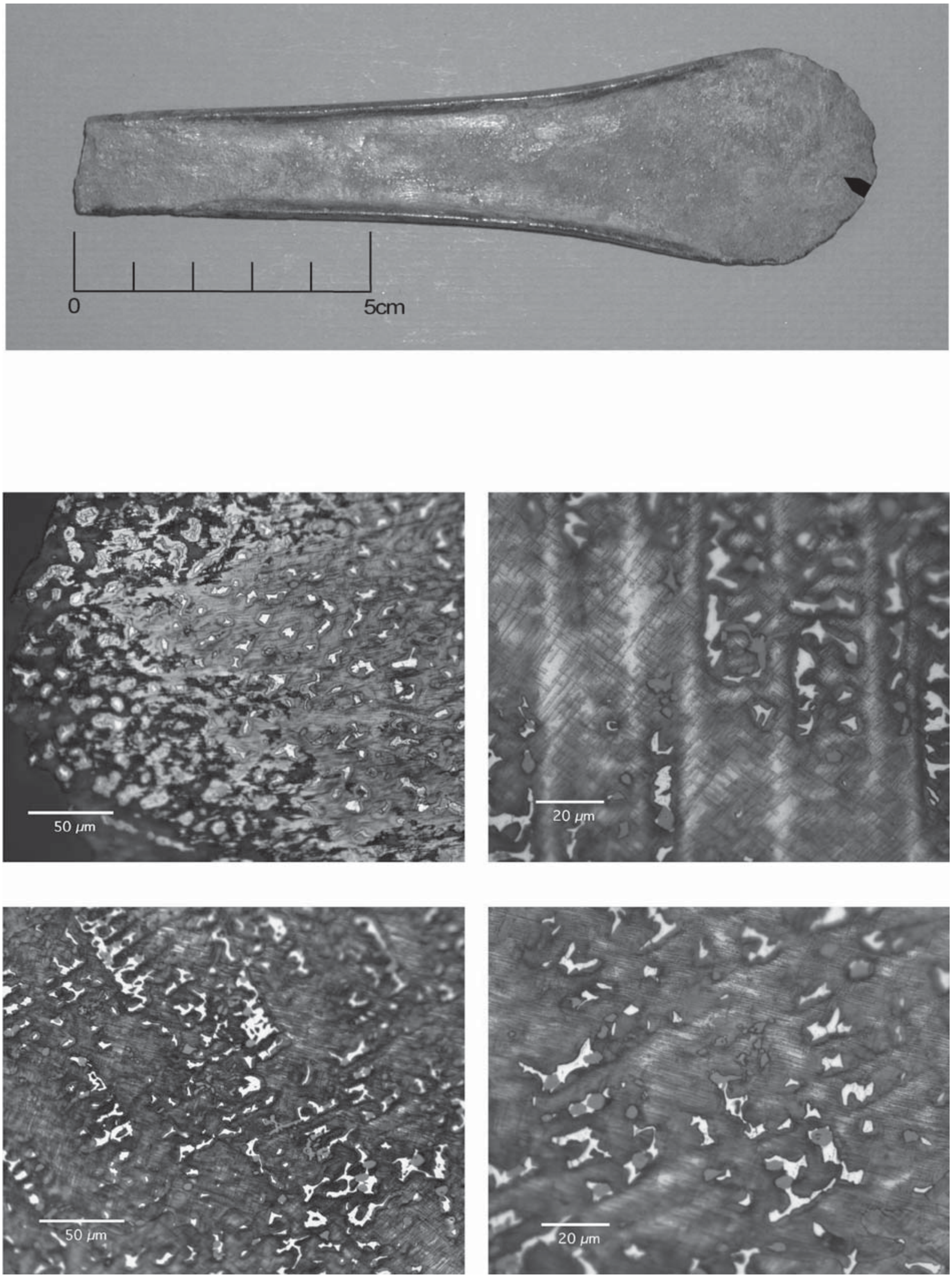
Tab. 87: Sample no. 28.



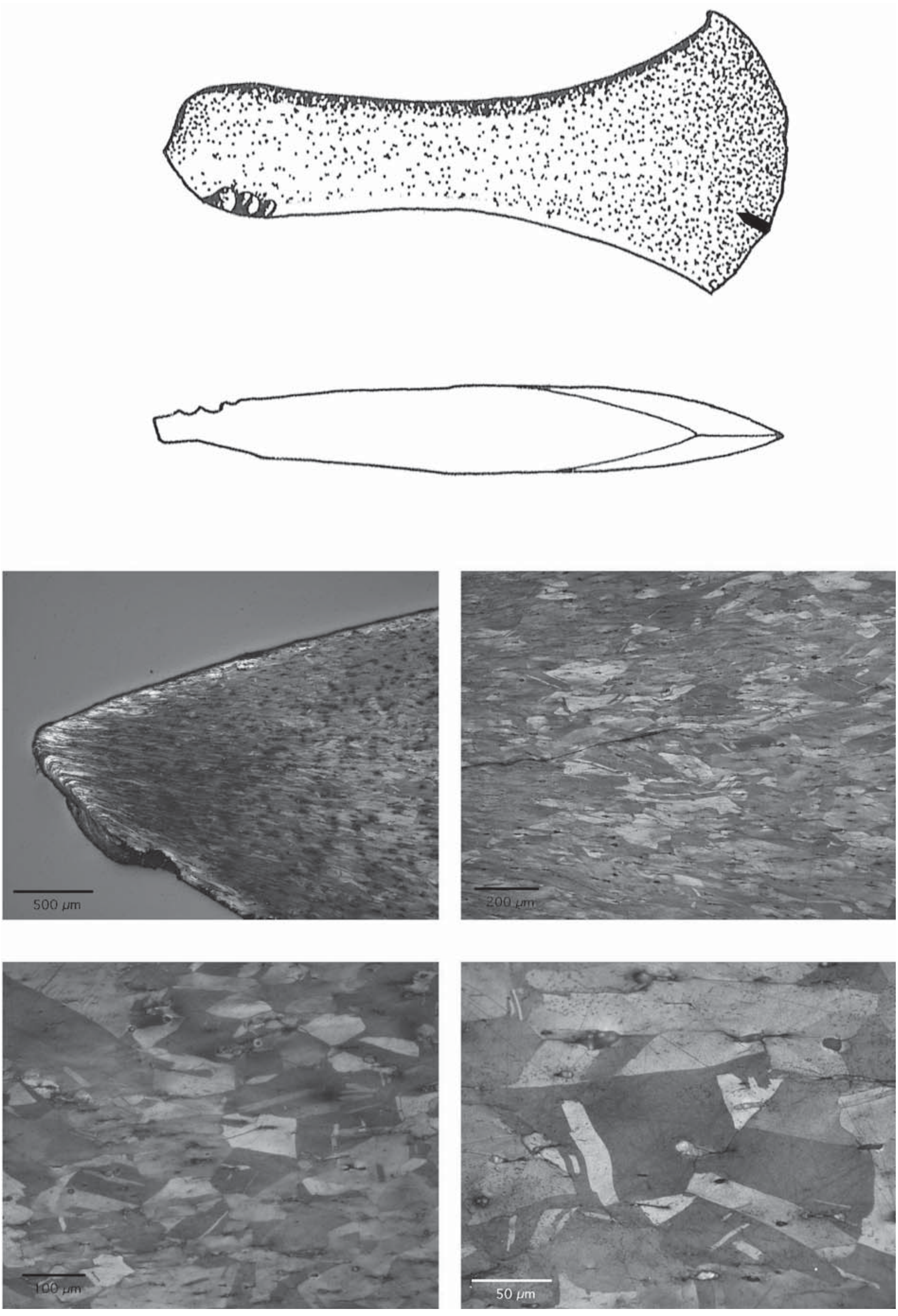
Tab. 88: Sample no. 34.



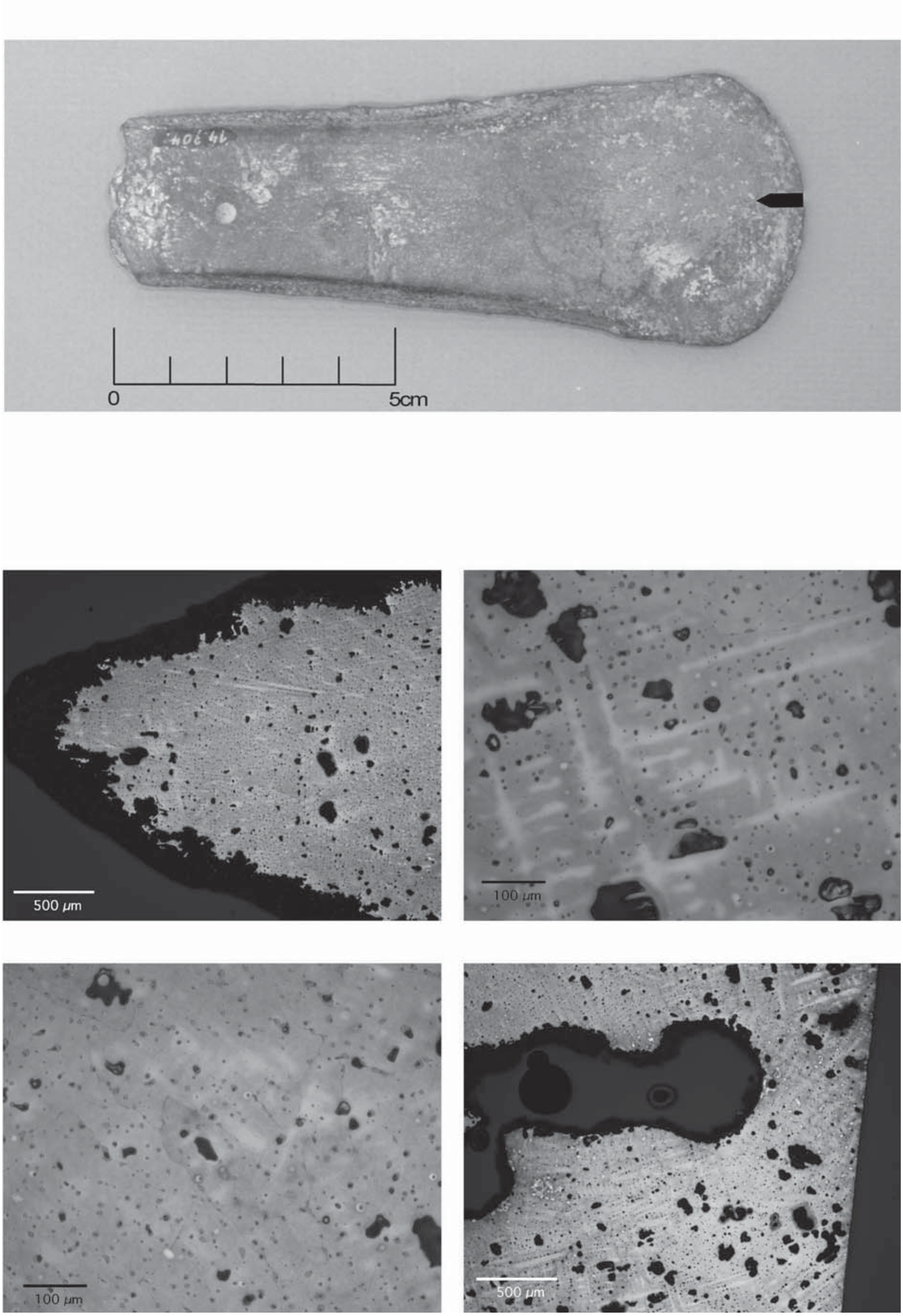
Tab. 89: Sample no. 51.



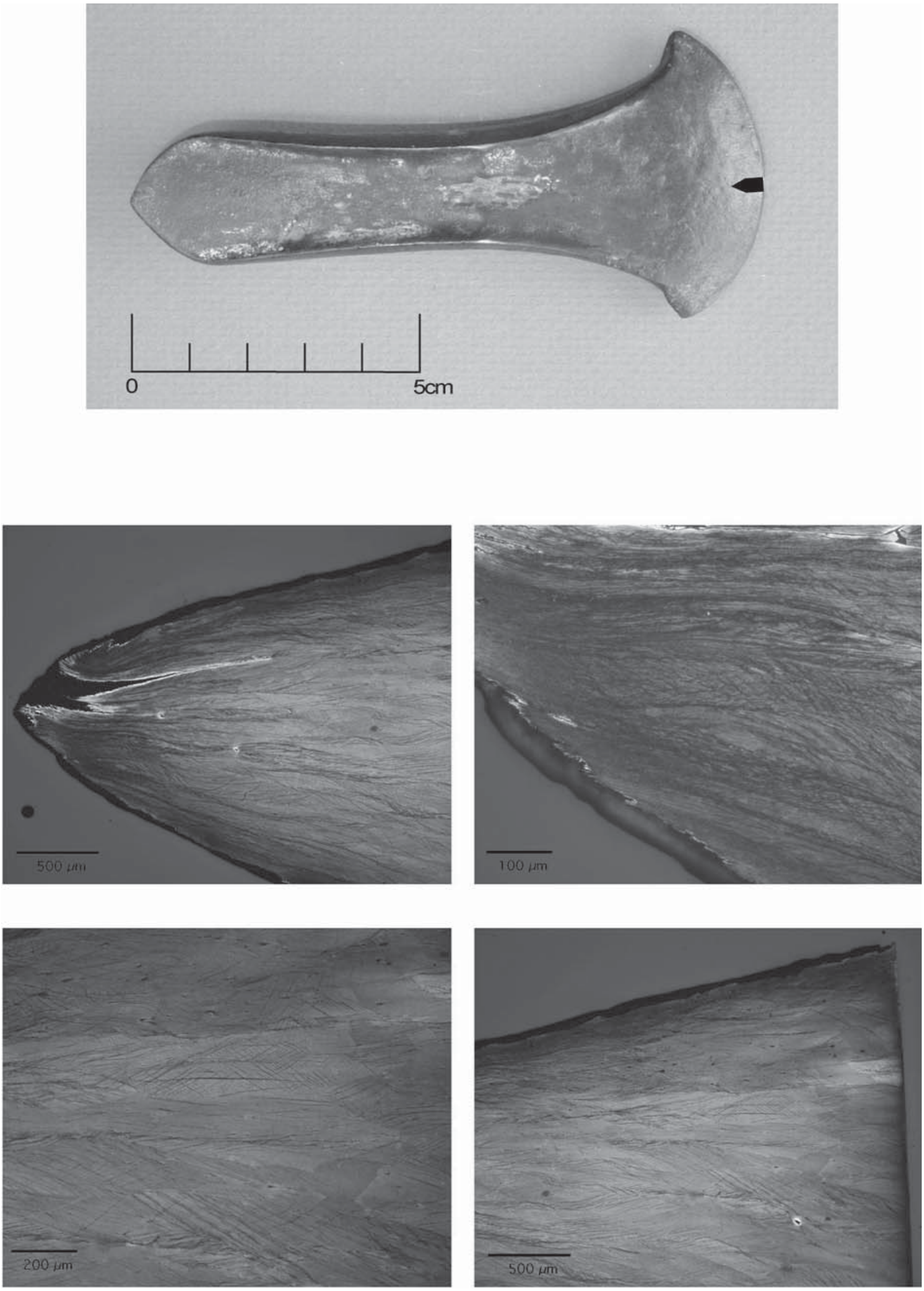
Tab. 90: Sample no. 54.



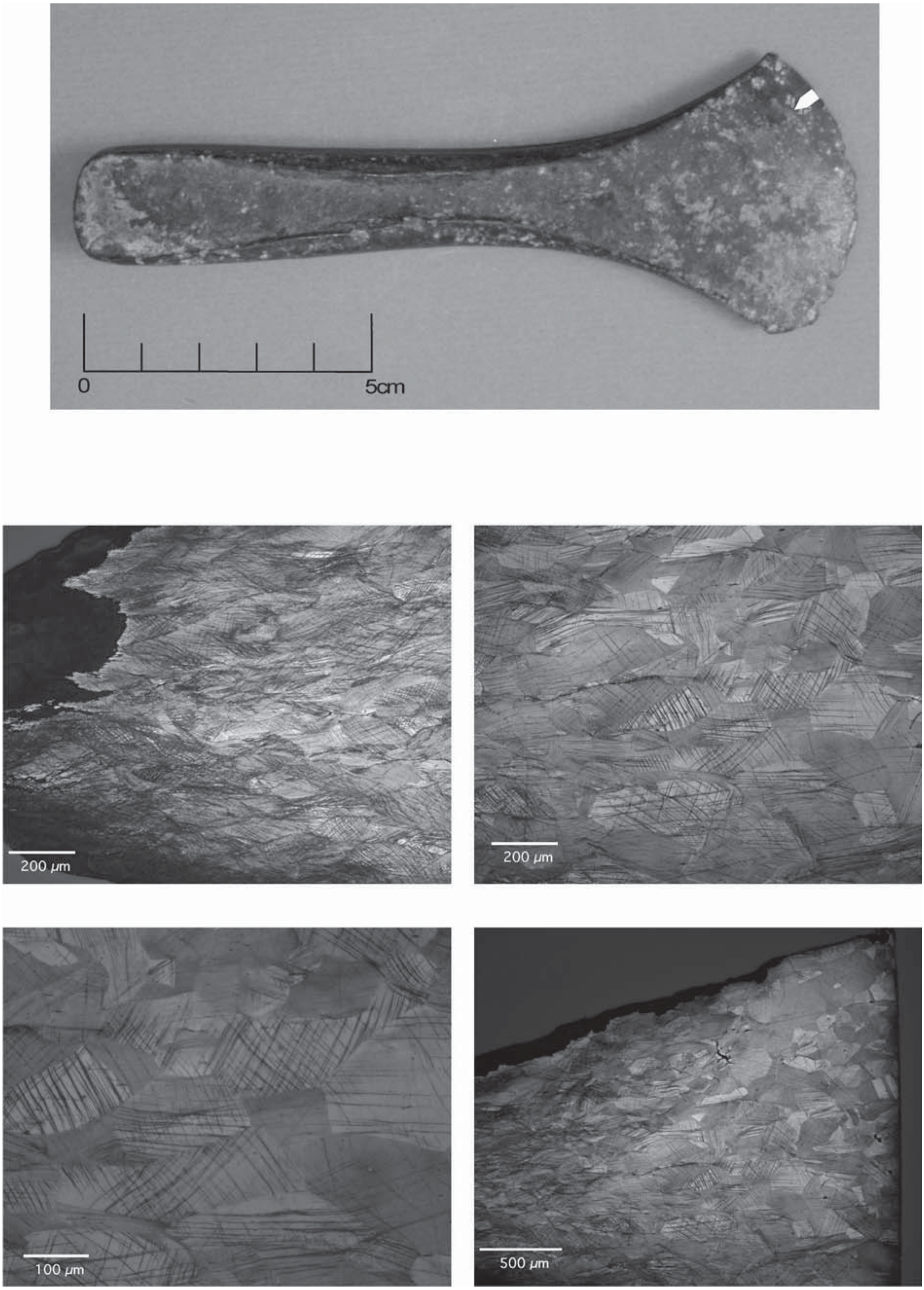
Tab. 91: Sample no. 69 (axe 1:1).



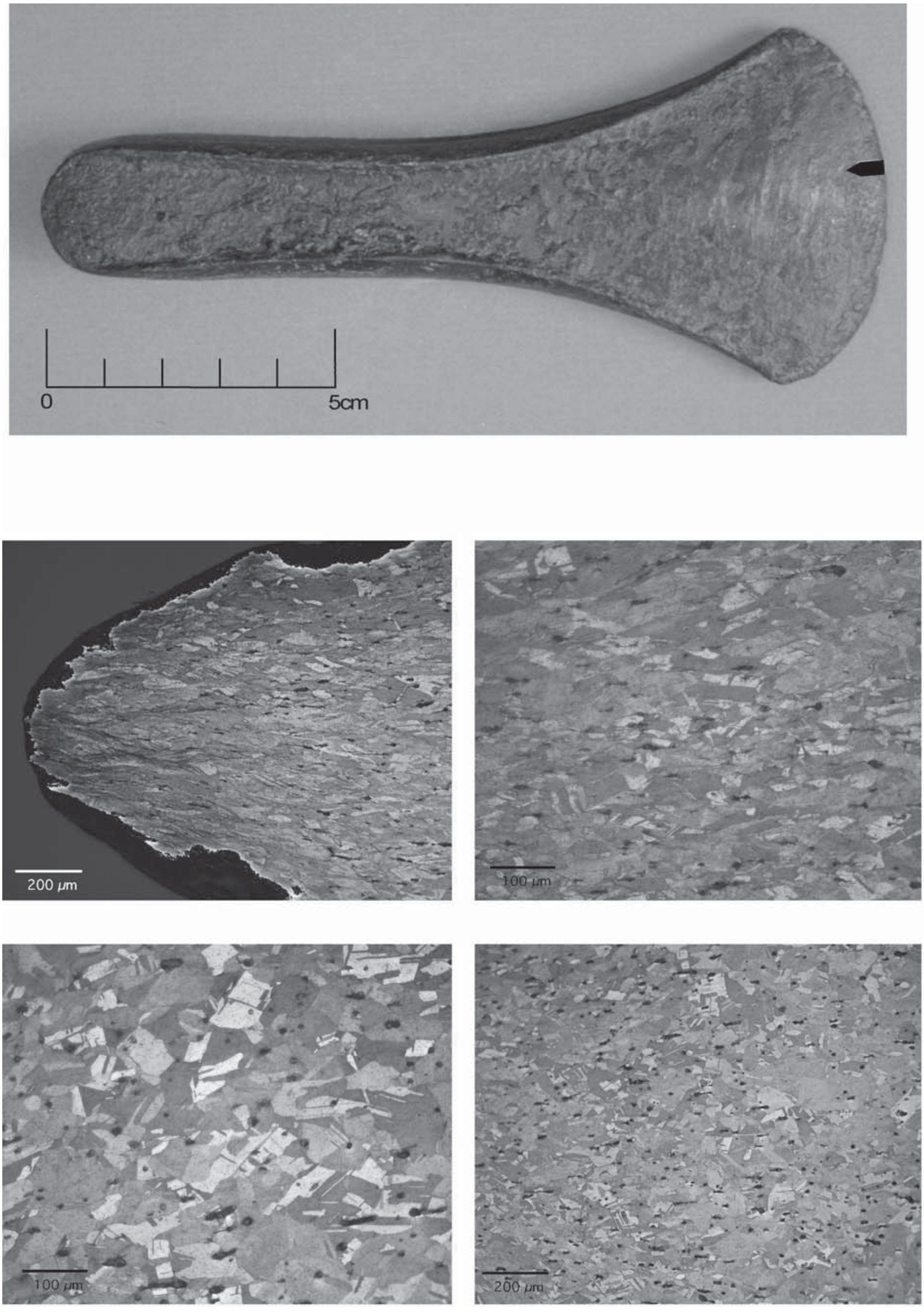
Tab. 92: Sample no. 75.



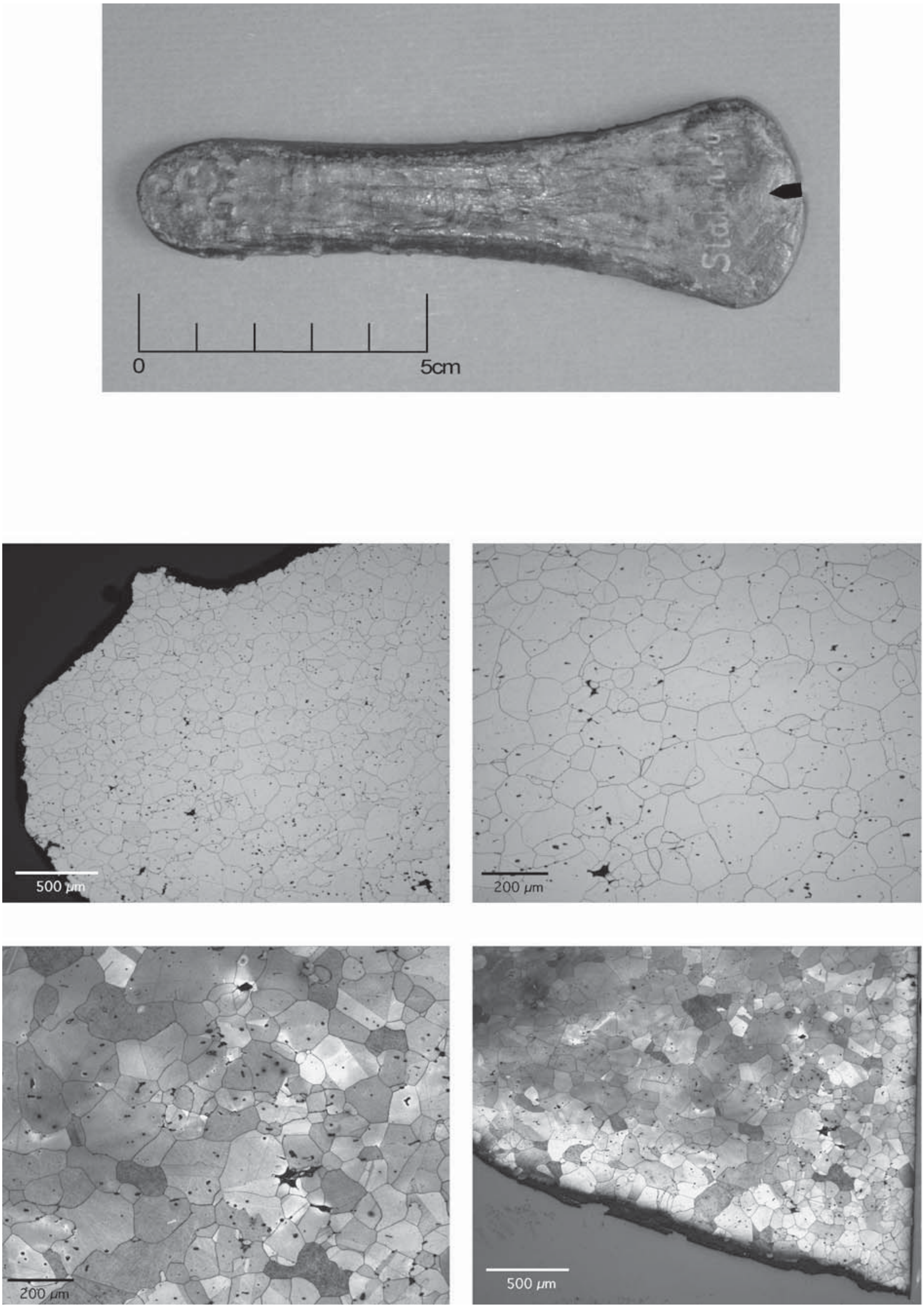
Tab. 93: Sample no. 114.



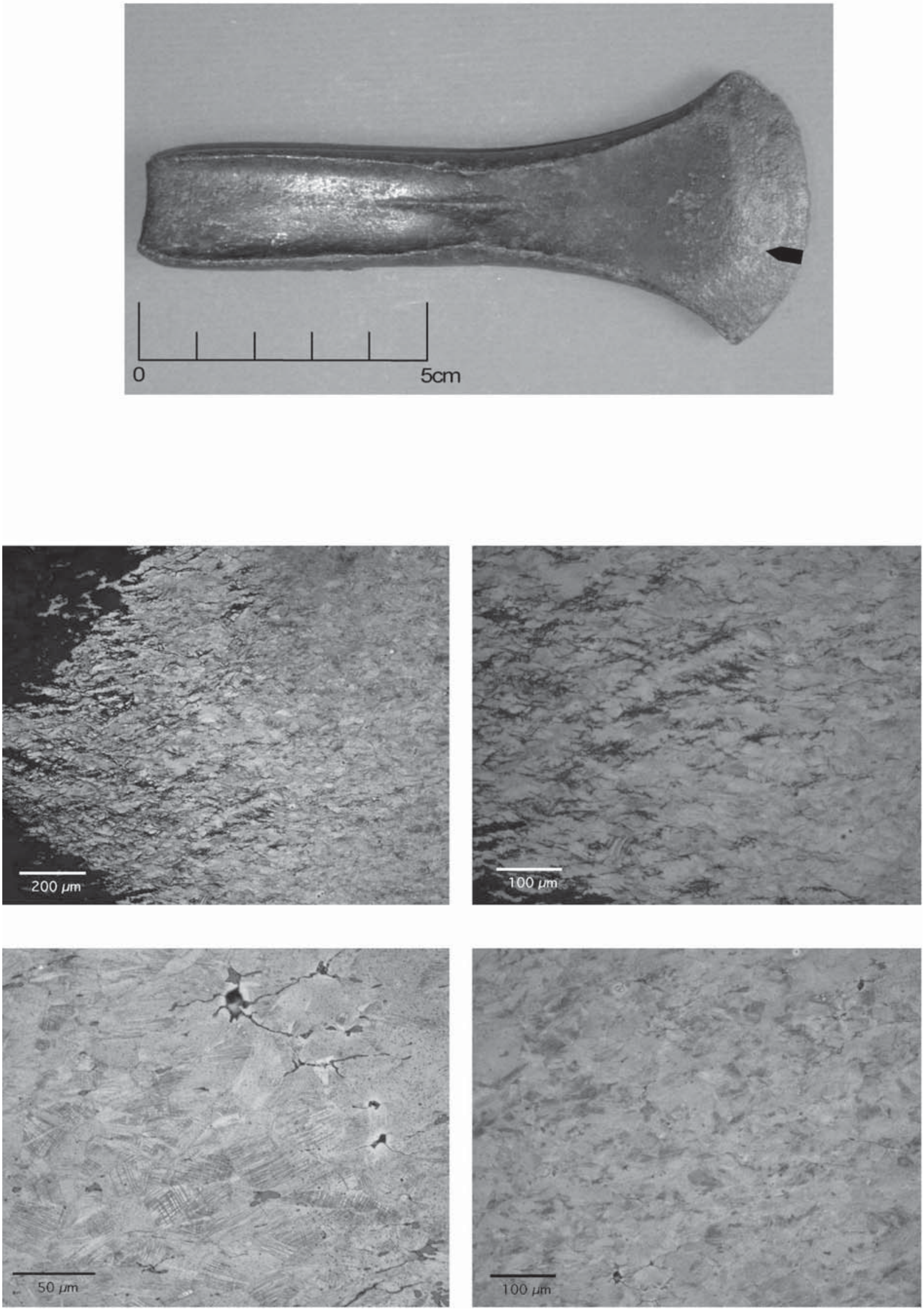
Tab. 94: Sample no. 119.



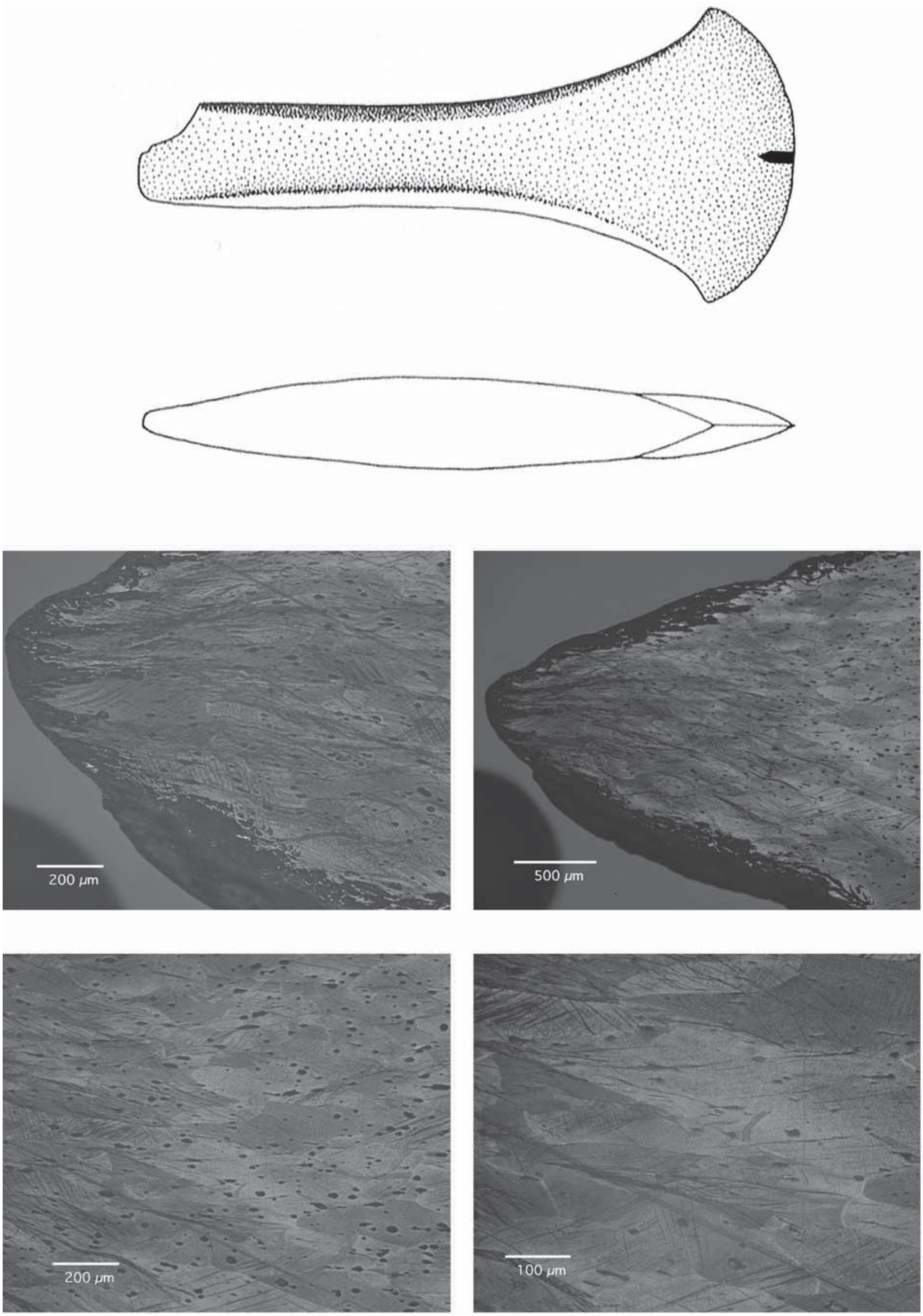
Tab. 95: Sample no. 124.



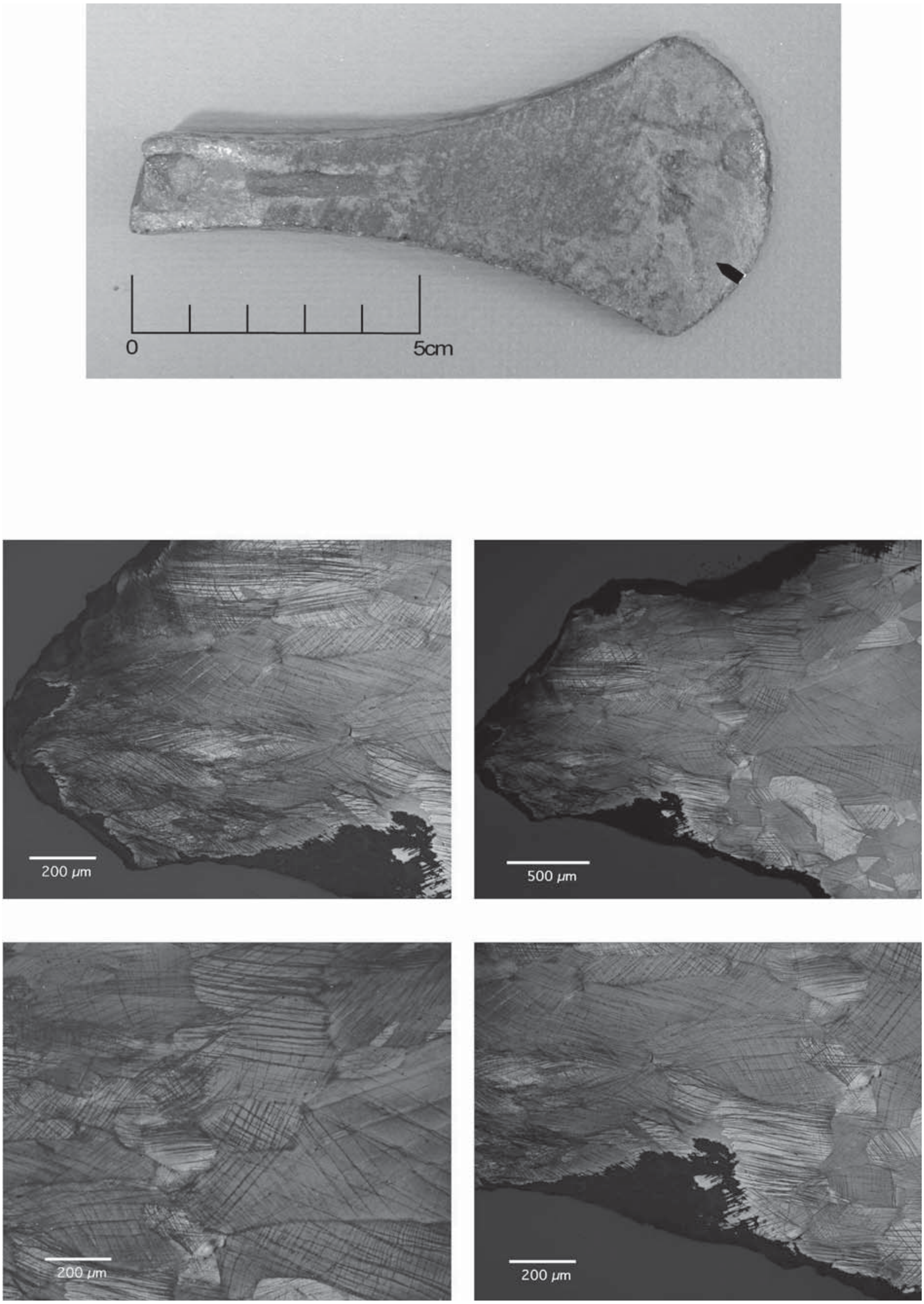
Tab. 96: Sample no. 125.



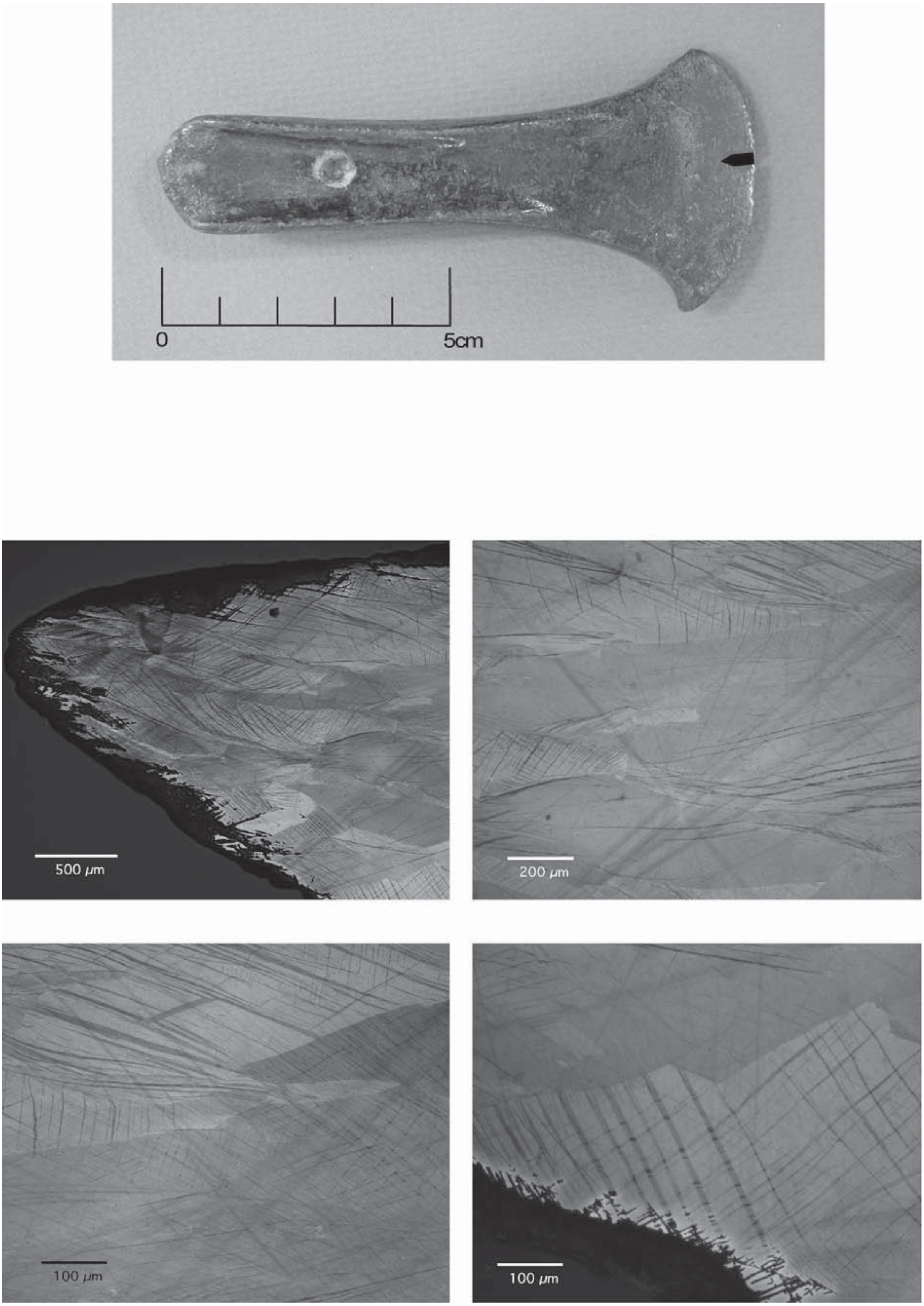
Tab. 97: Sample no. 126.



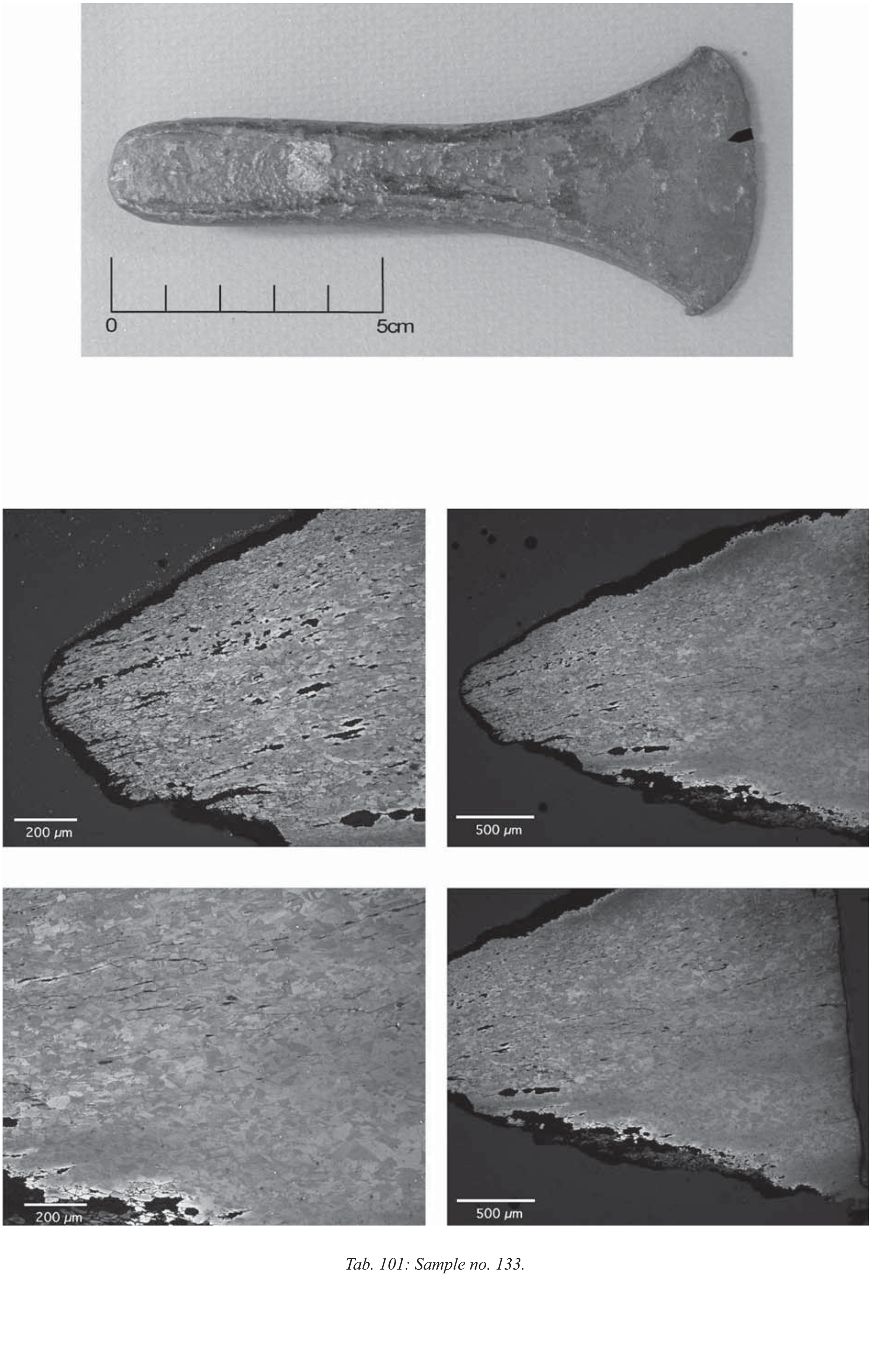
Tab. 98: Sample no. 127 (axe 1:1).



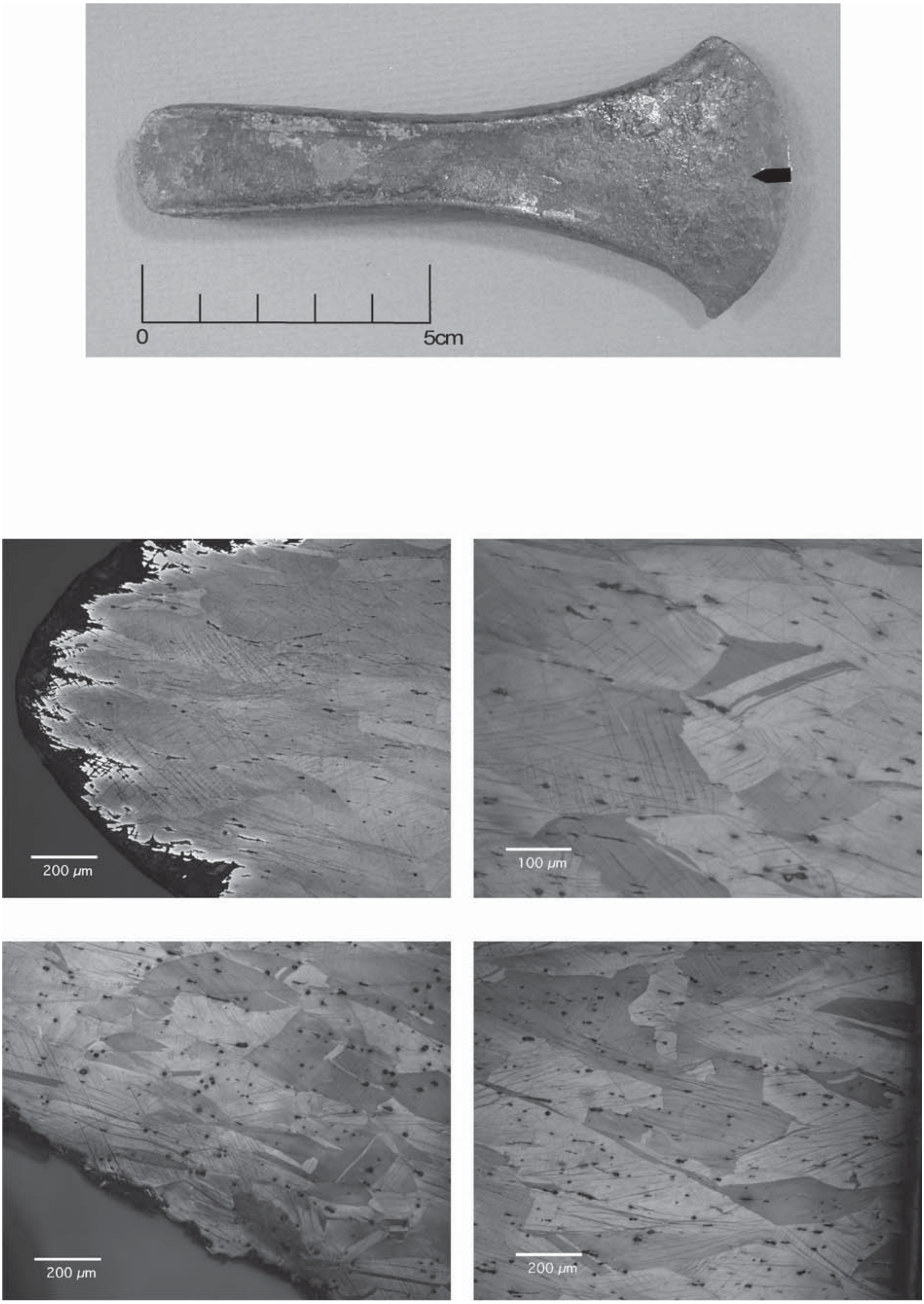
Tab. 99: Sample no. 131.



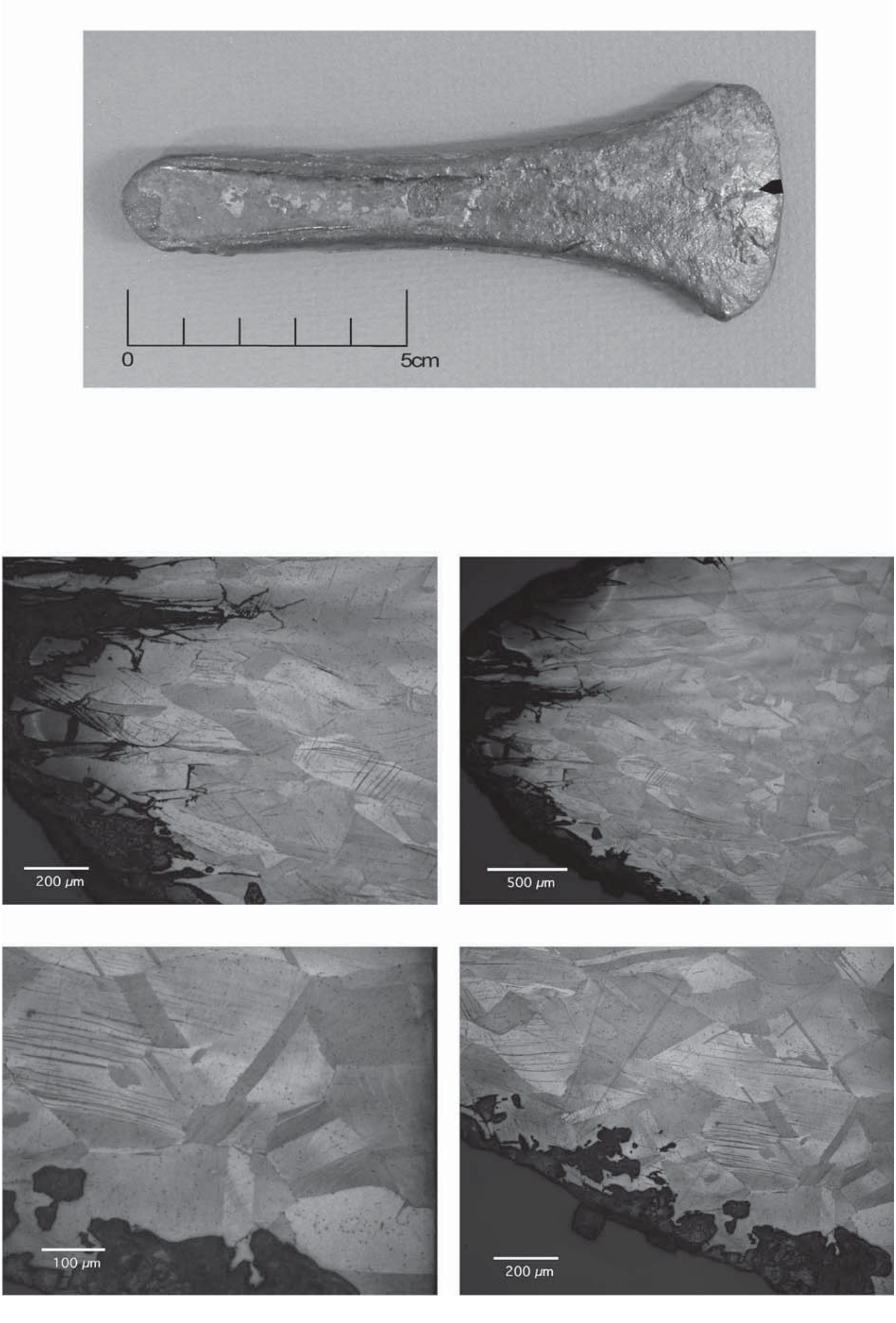
Tab. 100: Sample no. 132.



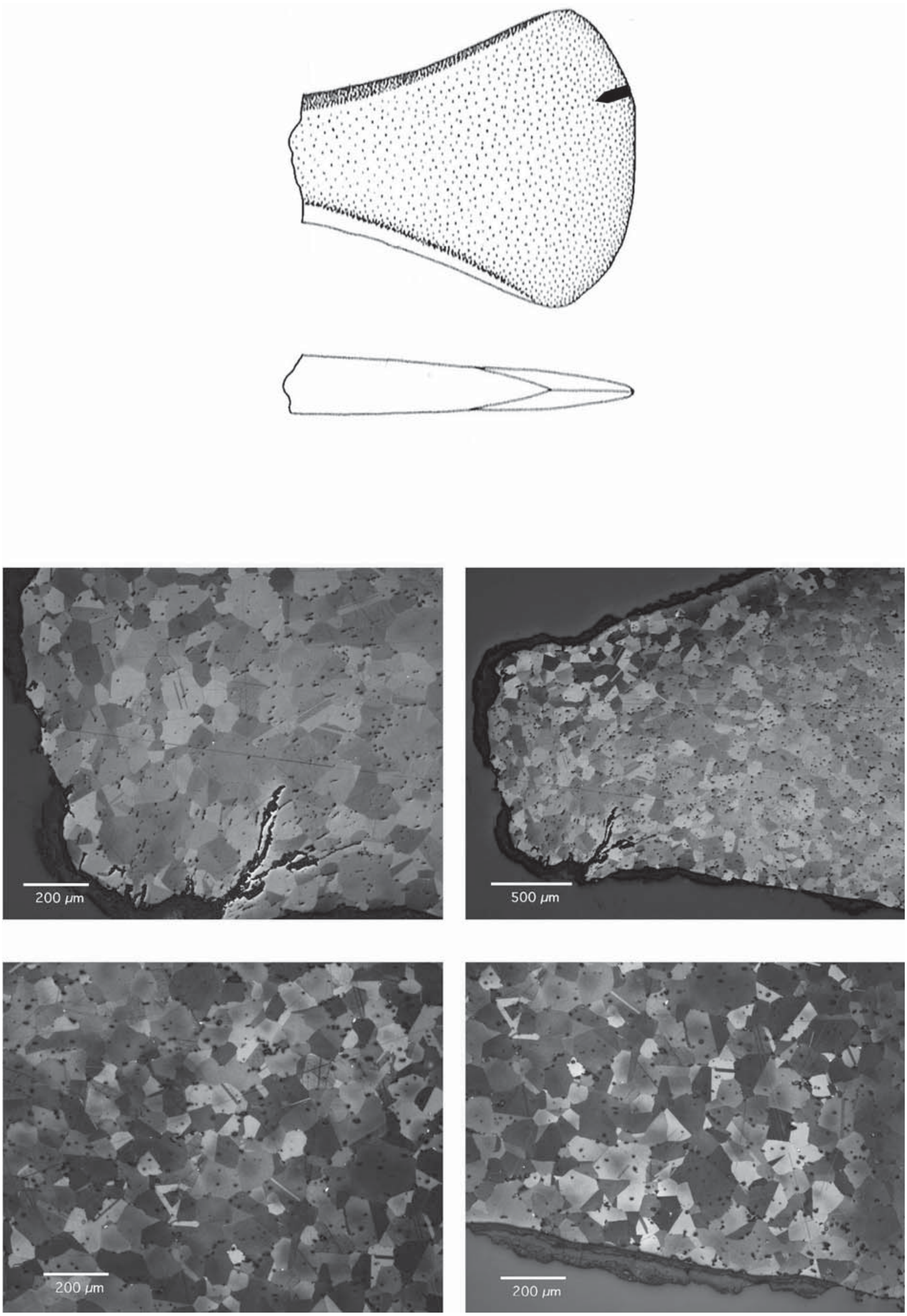
Tab. 101: Sample no. 133.



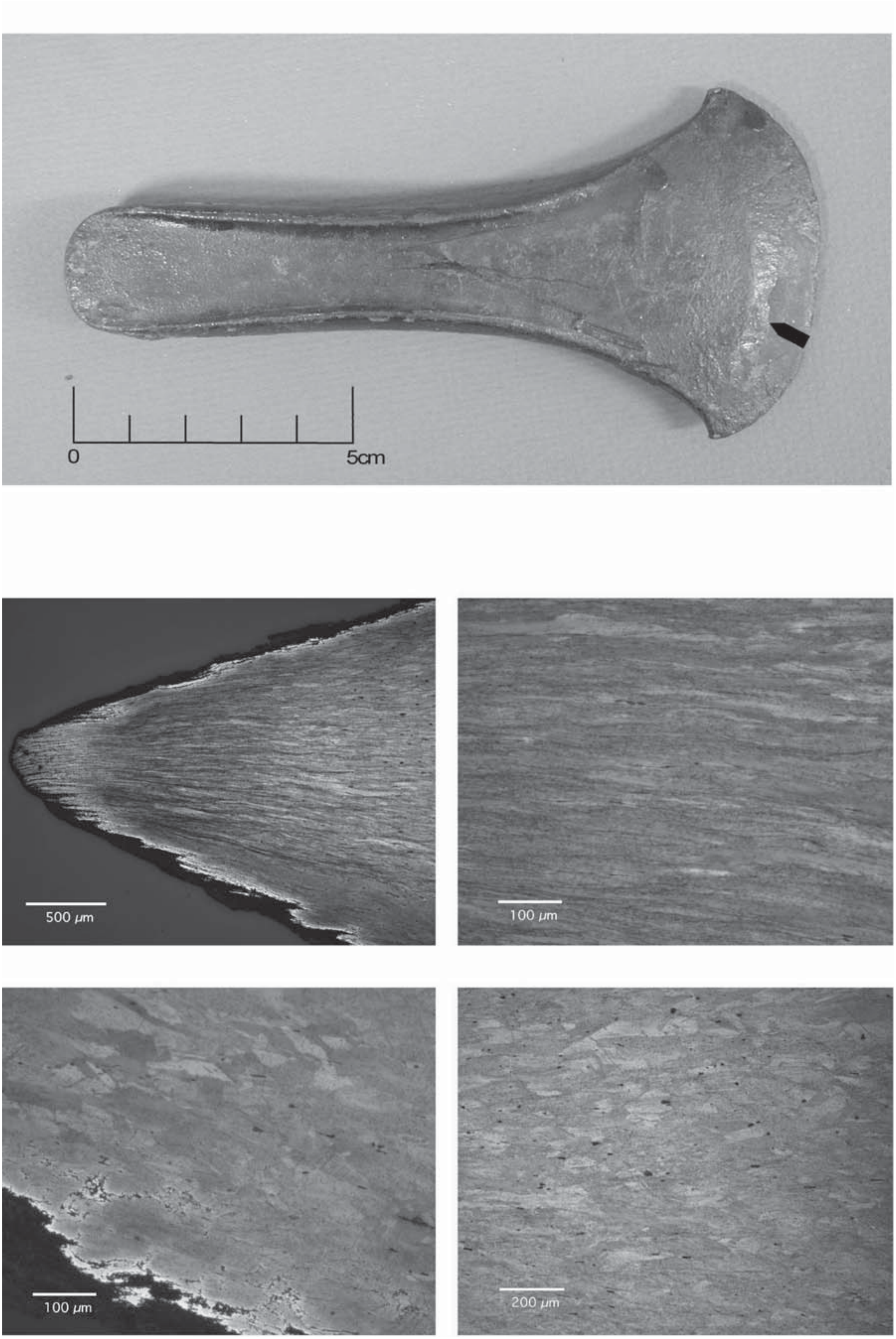
Tab. 102: Sample no. 135.



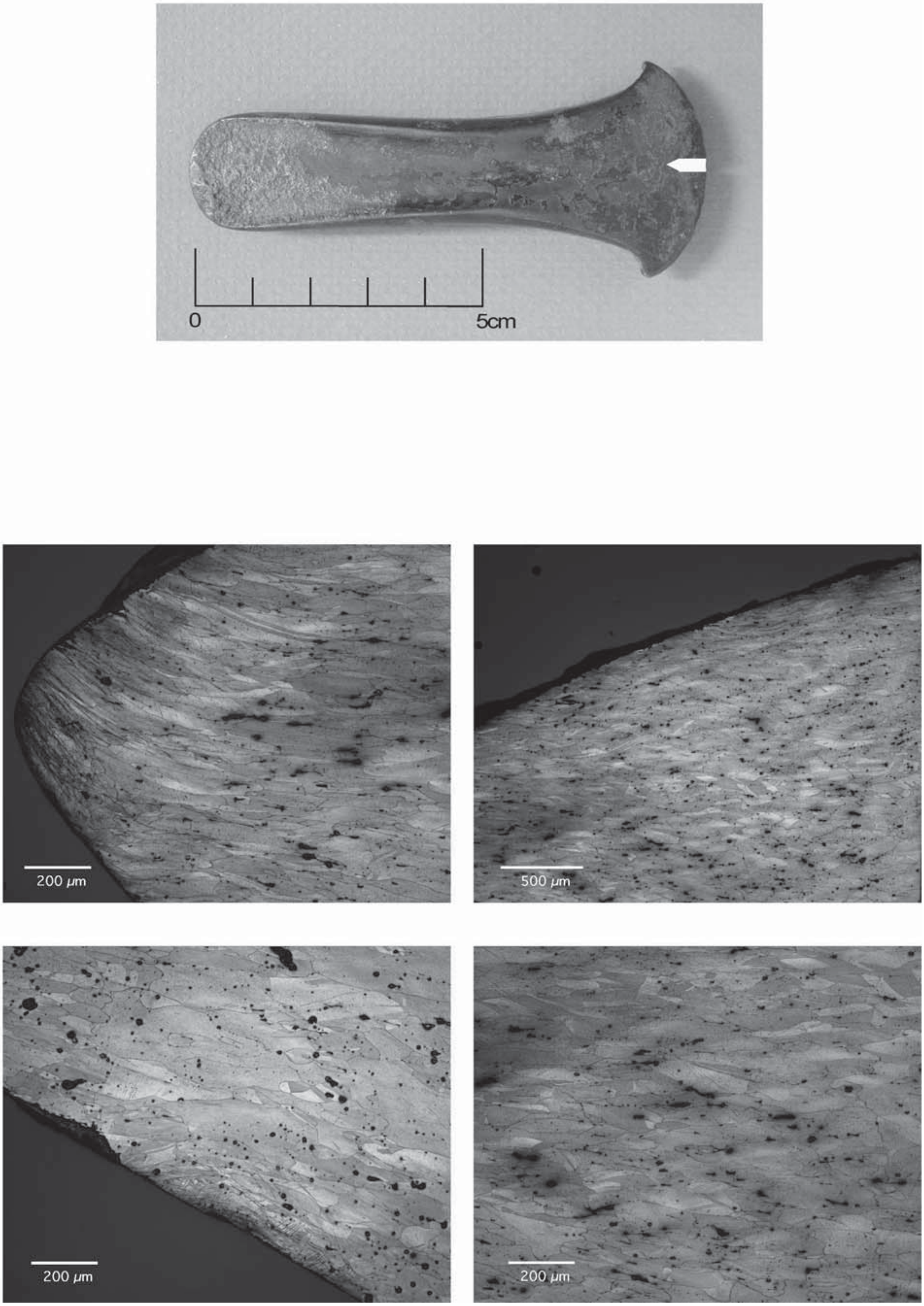
Tab. 103: Sample no. 145.



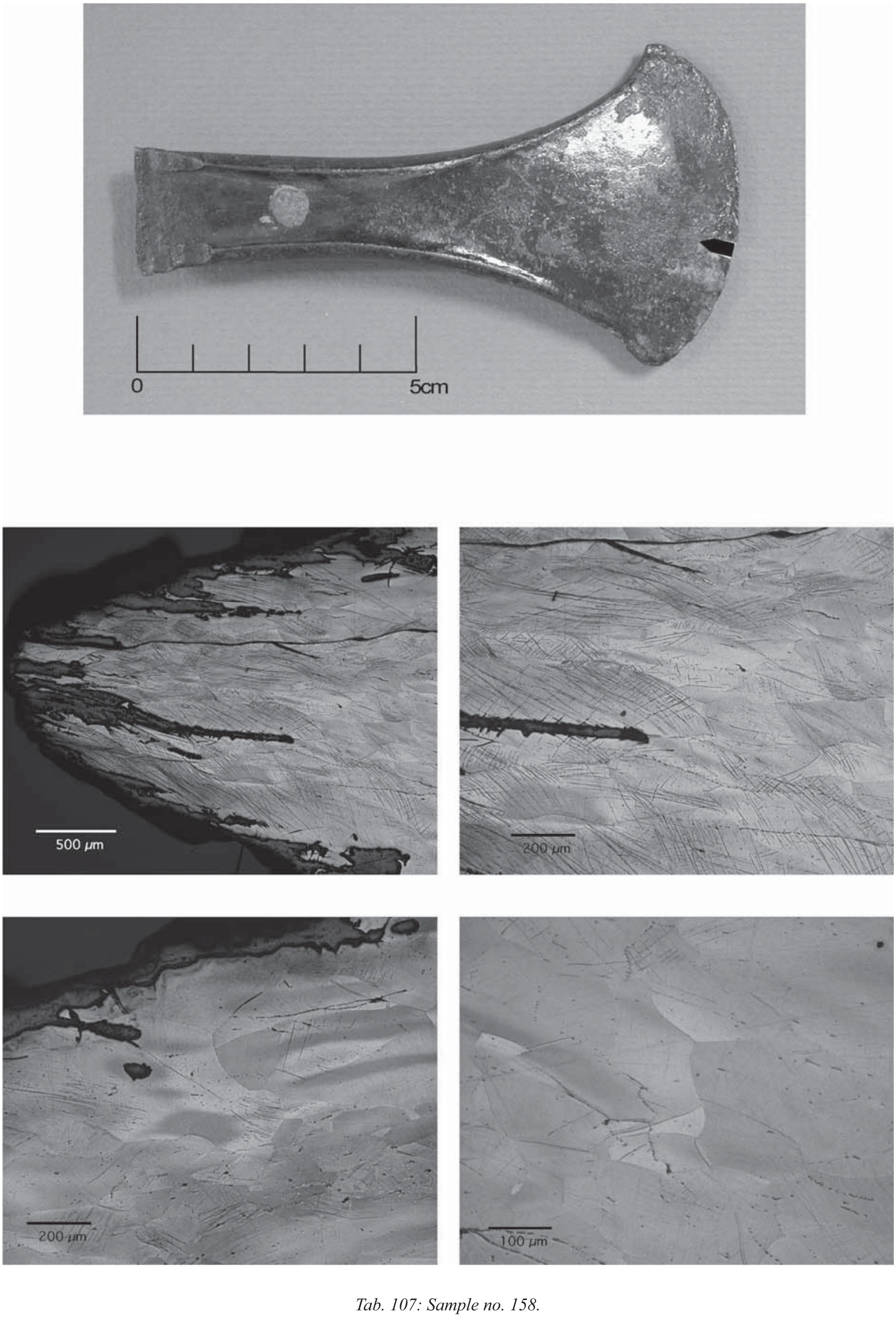
Tab. 104: Sample no. 146 (axe 1:1).



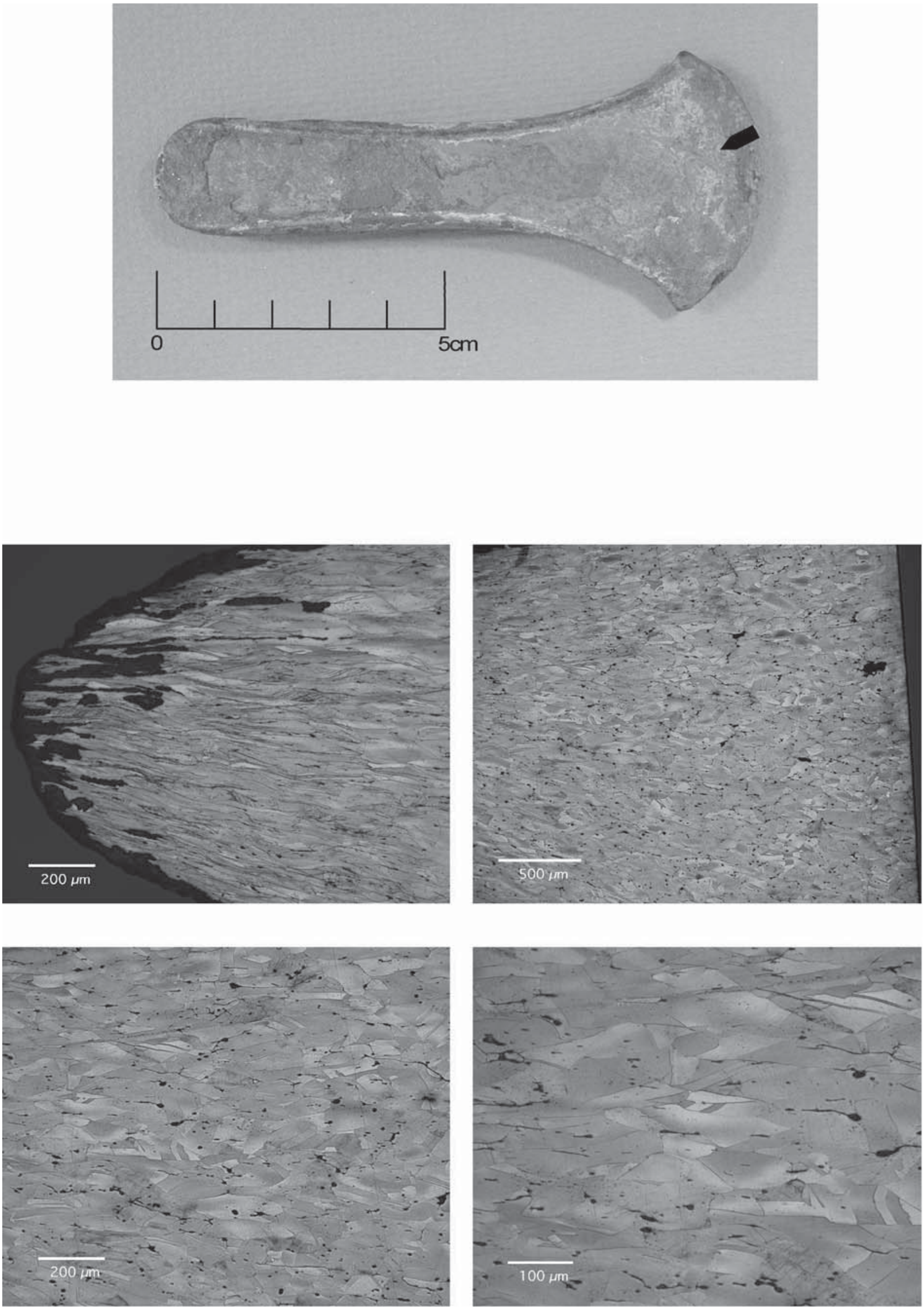
Tab. 105: Sample no. 151.



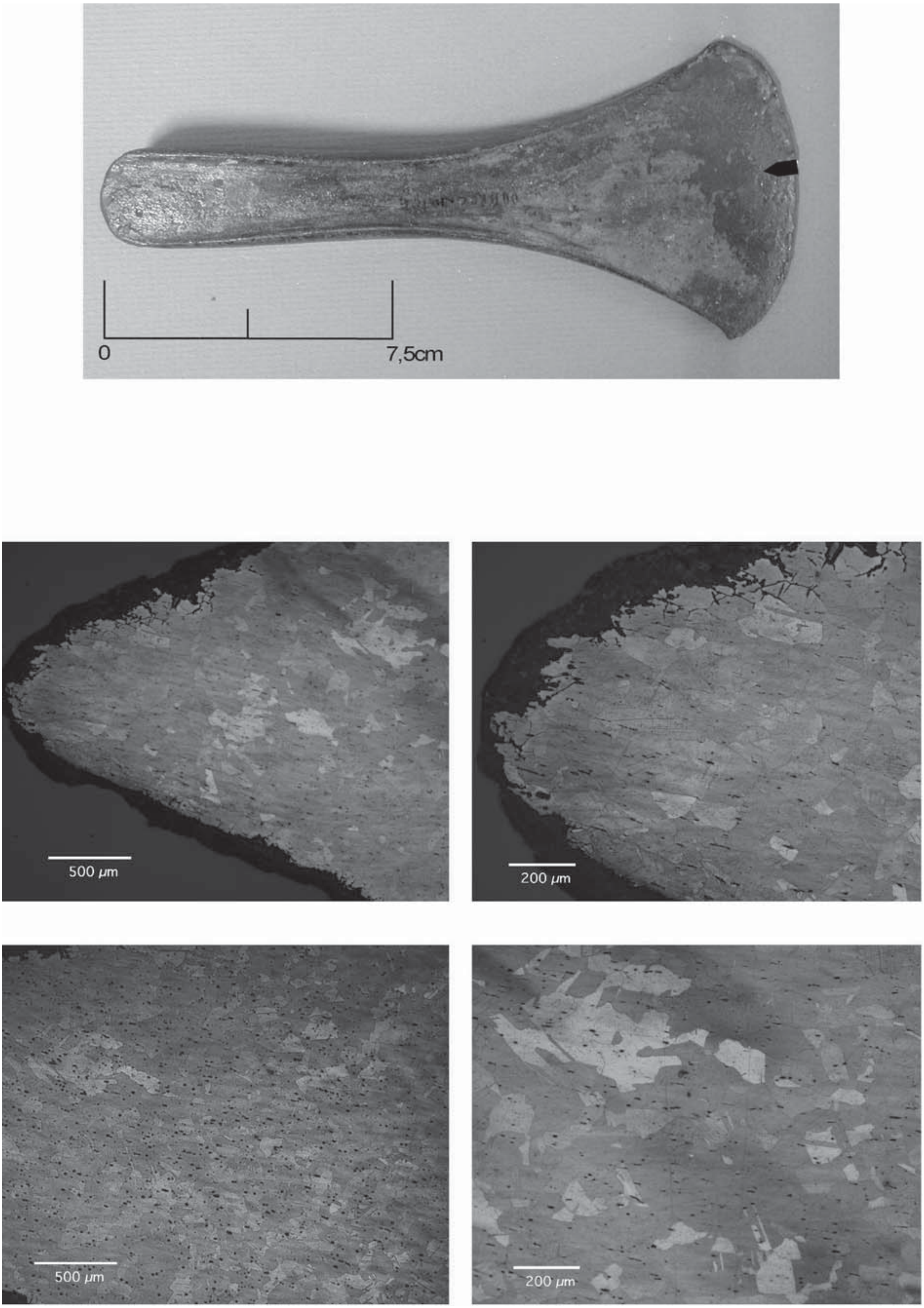
Tab. 106: Sample no. 152.



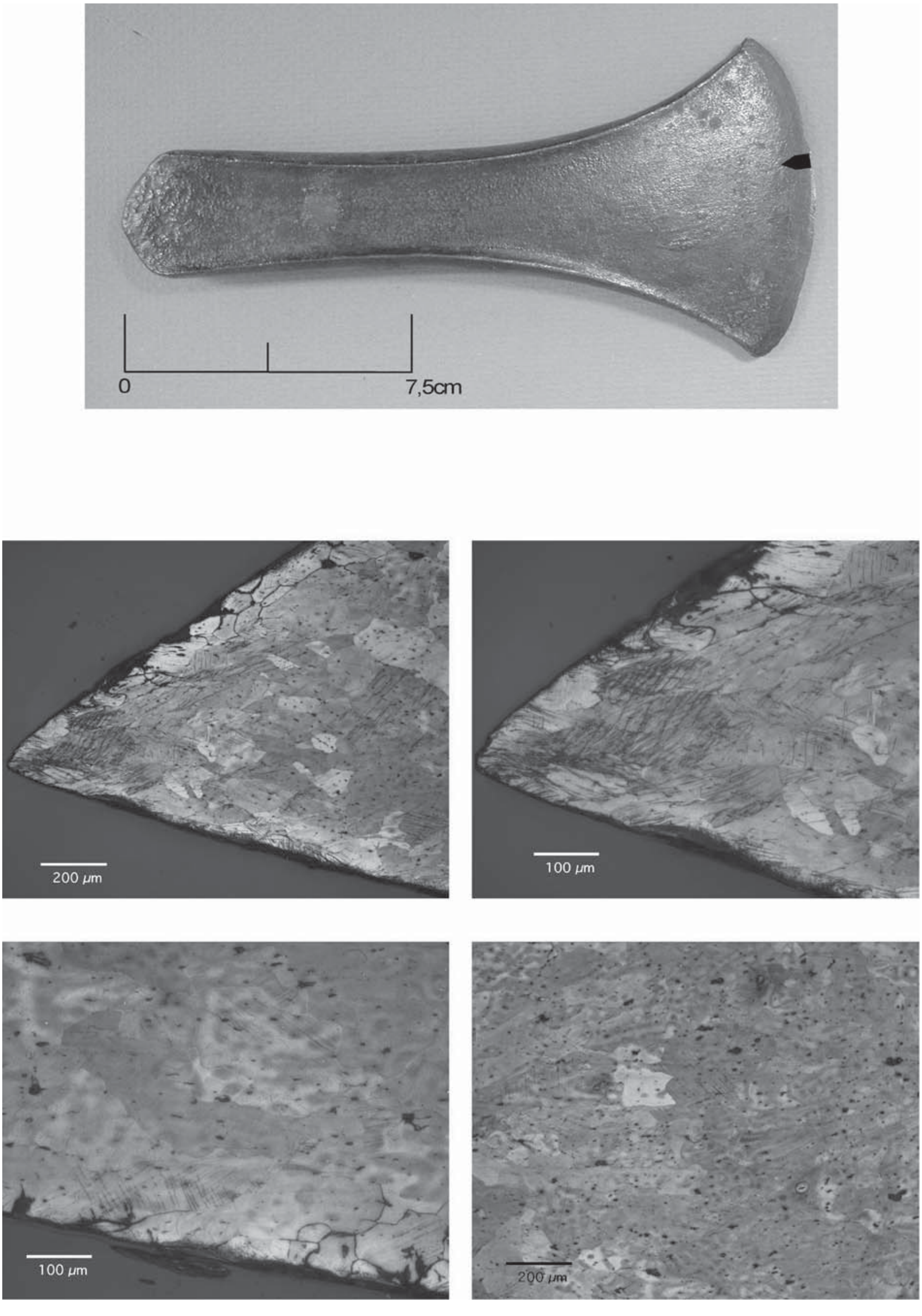
Tab. 107: Sample no. 158.



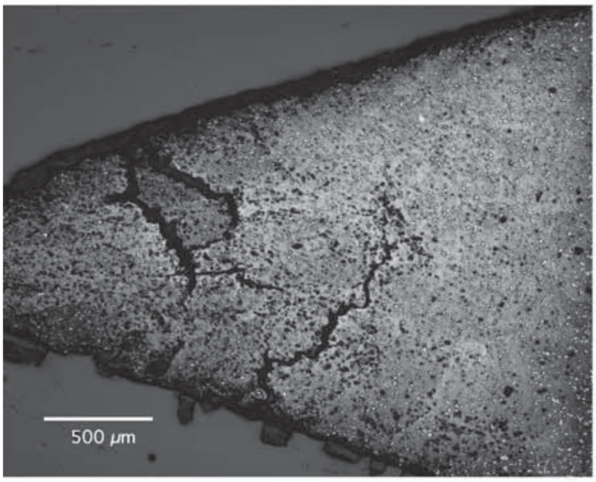
Tab. 108: Sample no. 159.

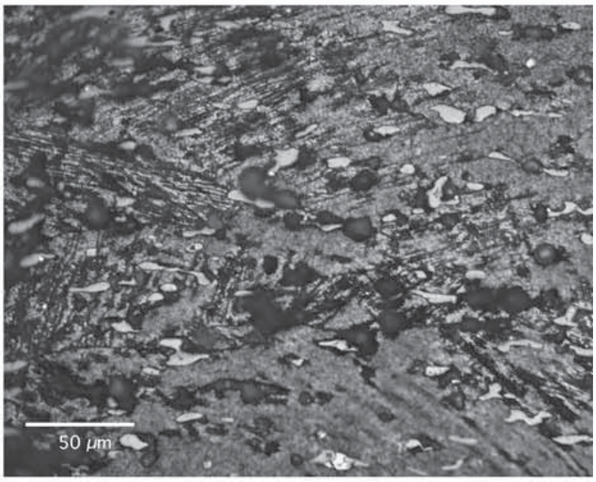


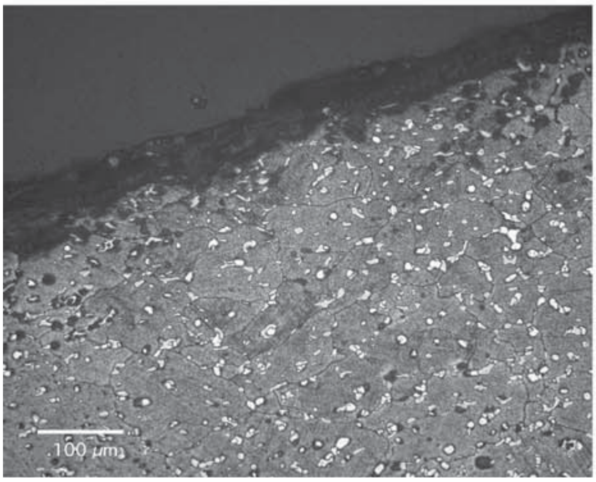
Tab. 109: Sample no. 162.

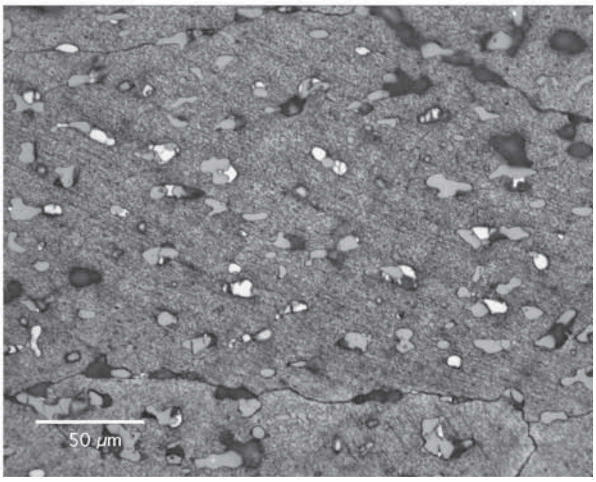


Tab. 110: Sample no. 163.

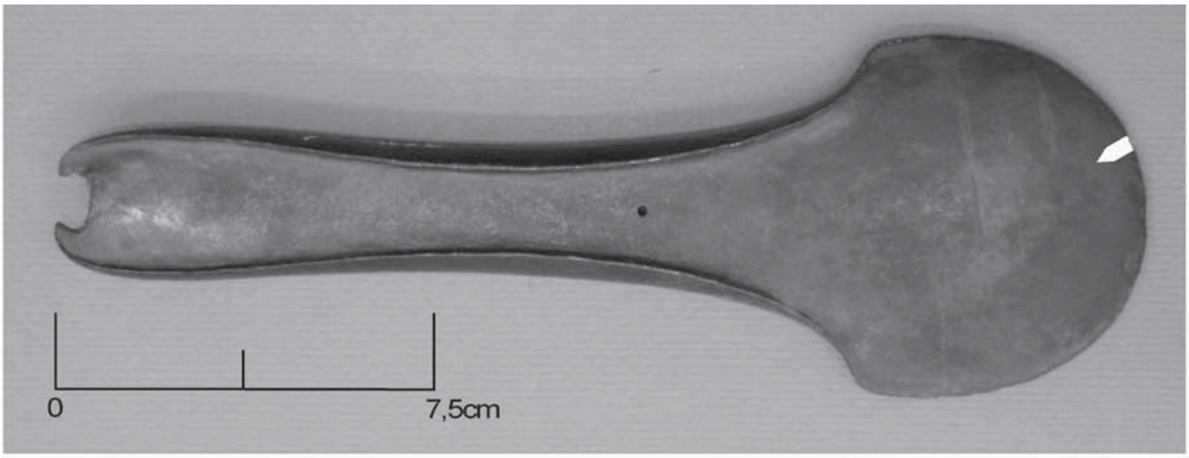


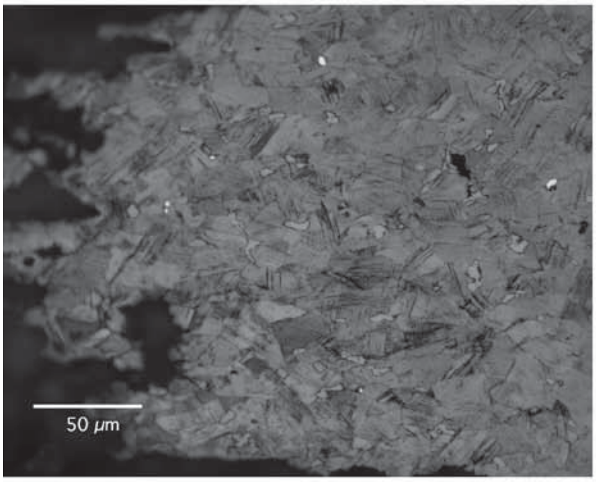


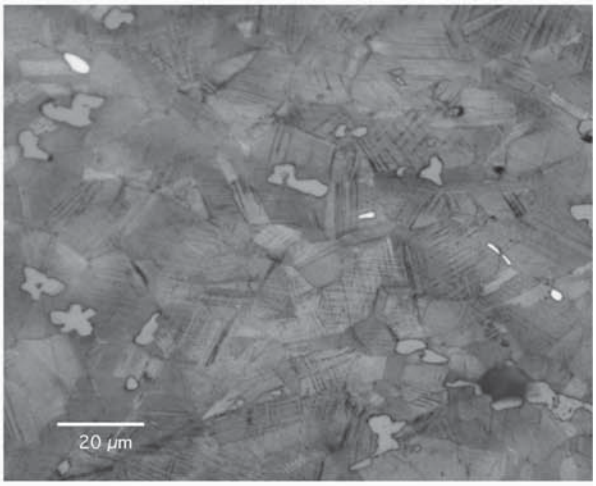


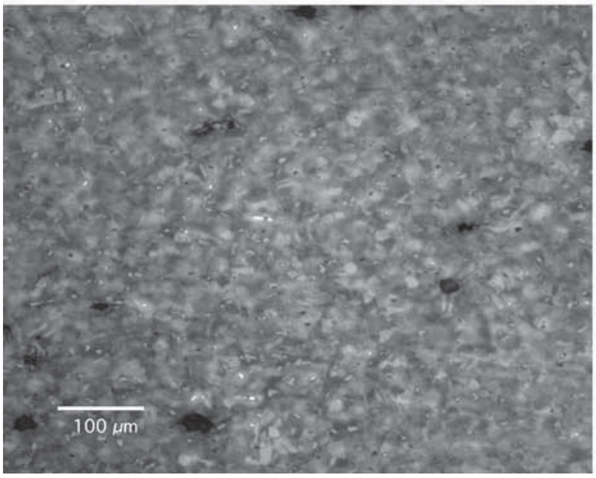


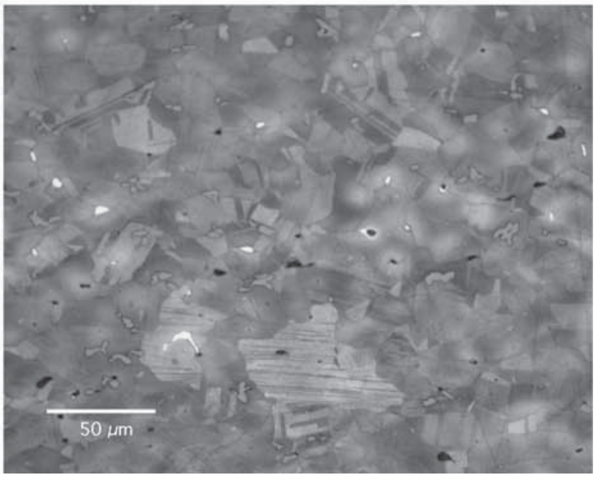
Tab. 111: Sample no. 166.



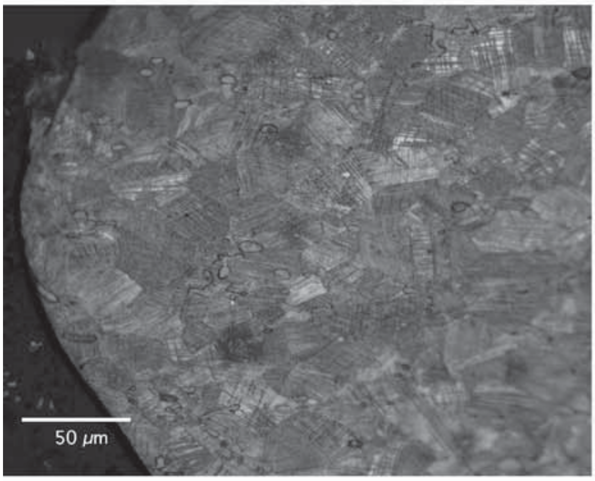


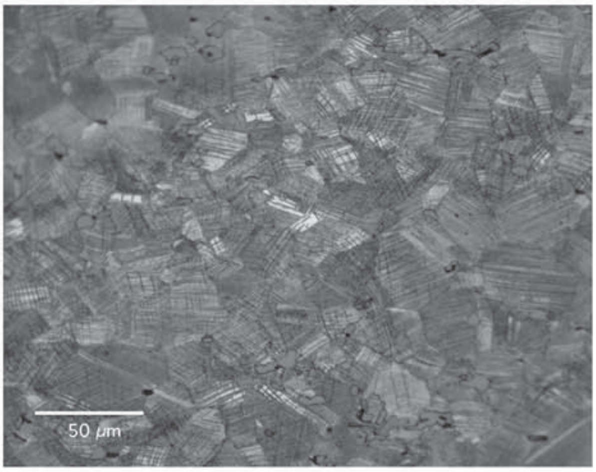


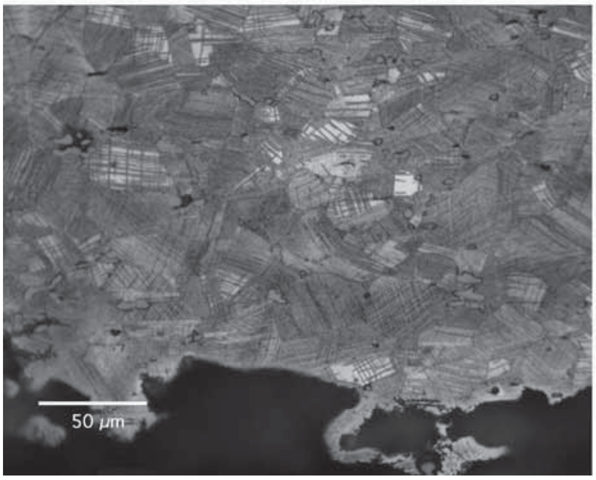


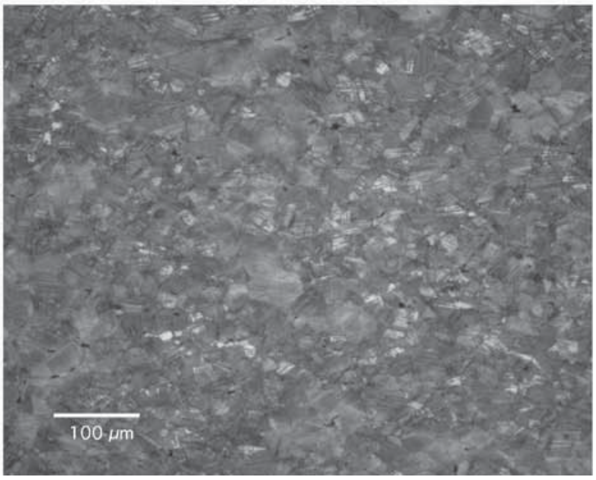


Tab. 112: Sample no. 167.

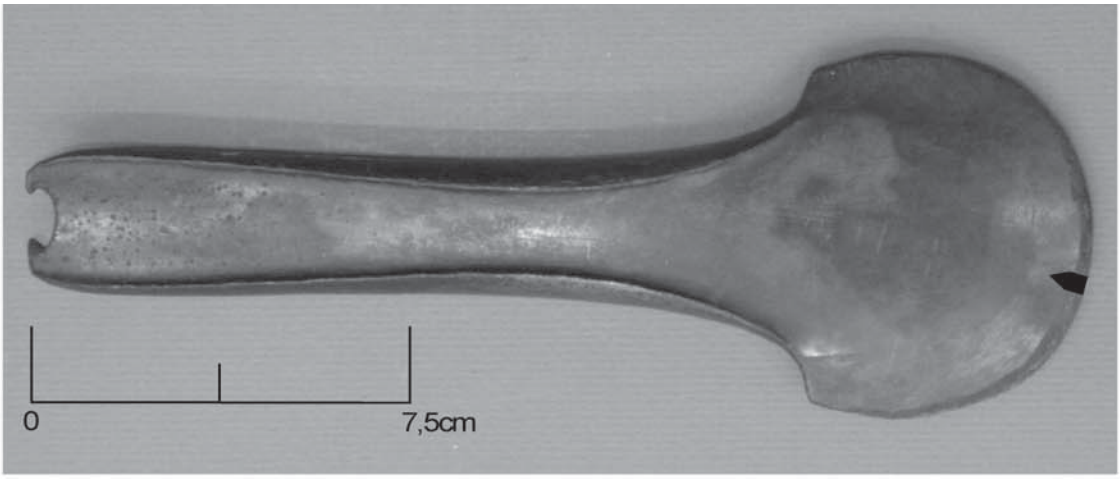


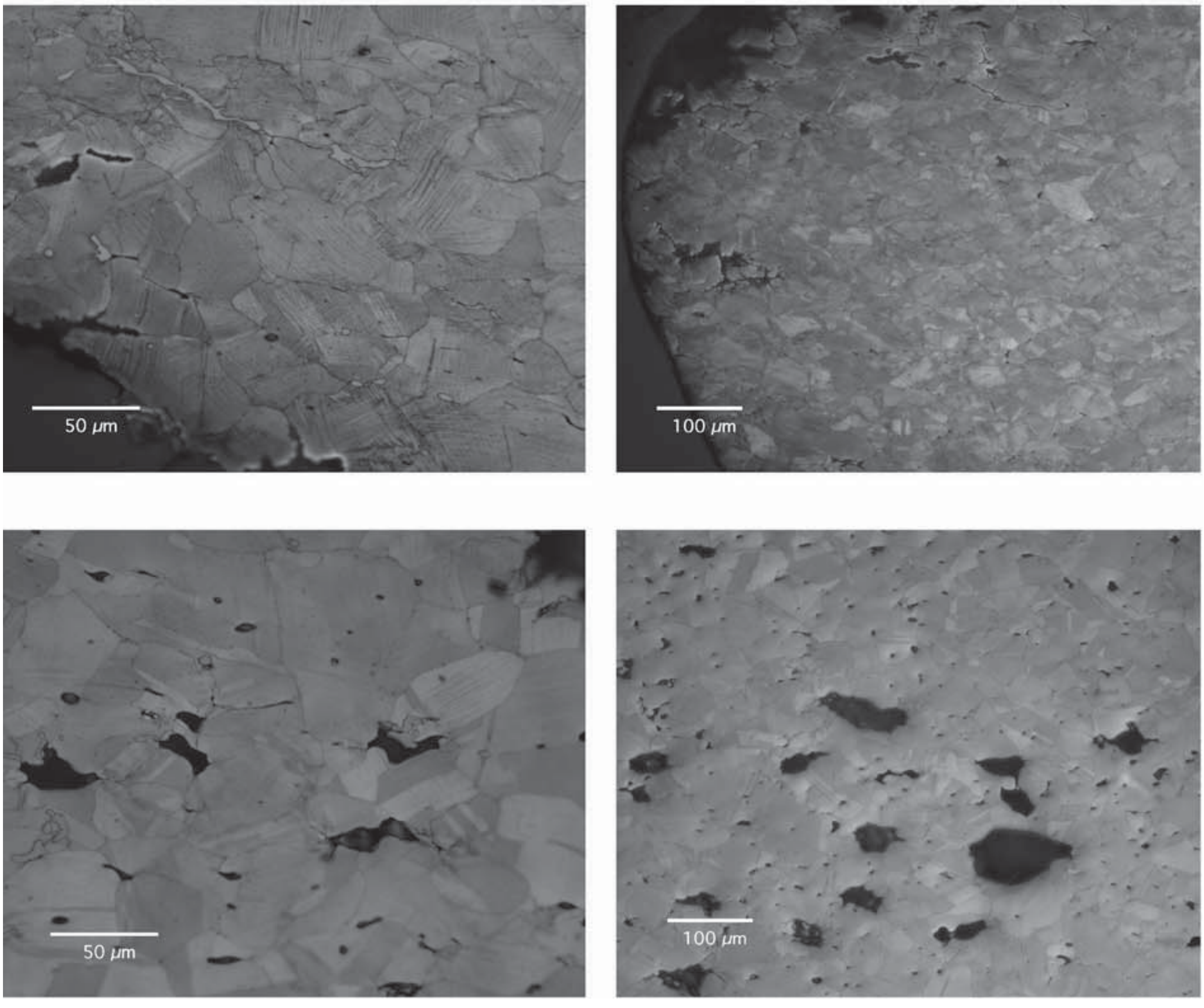




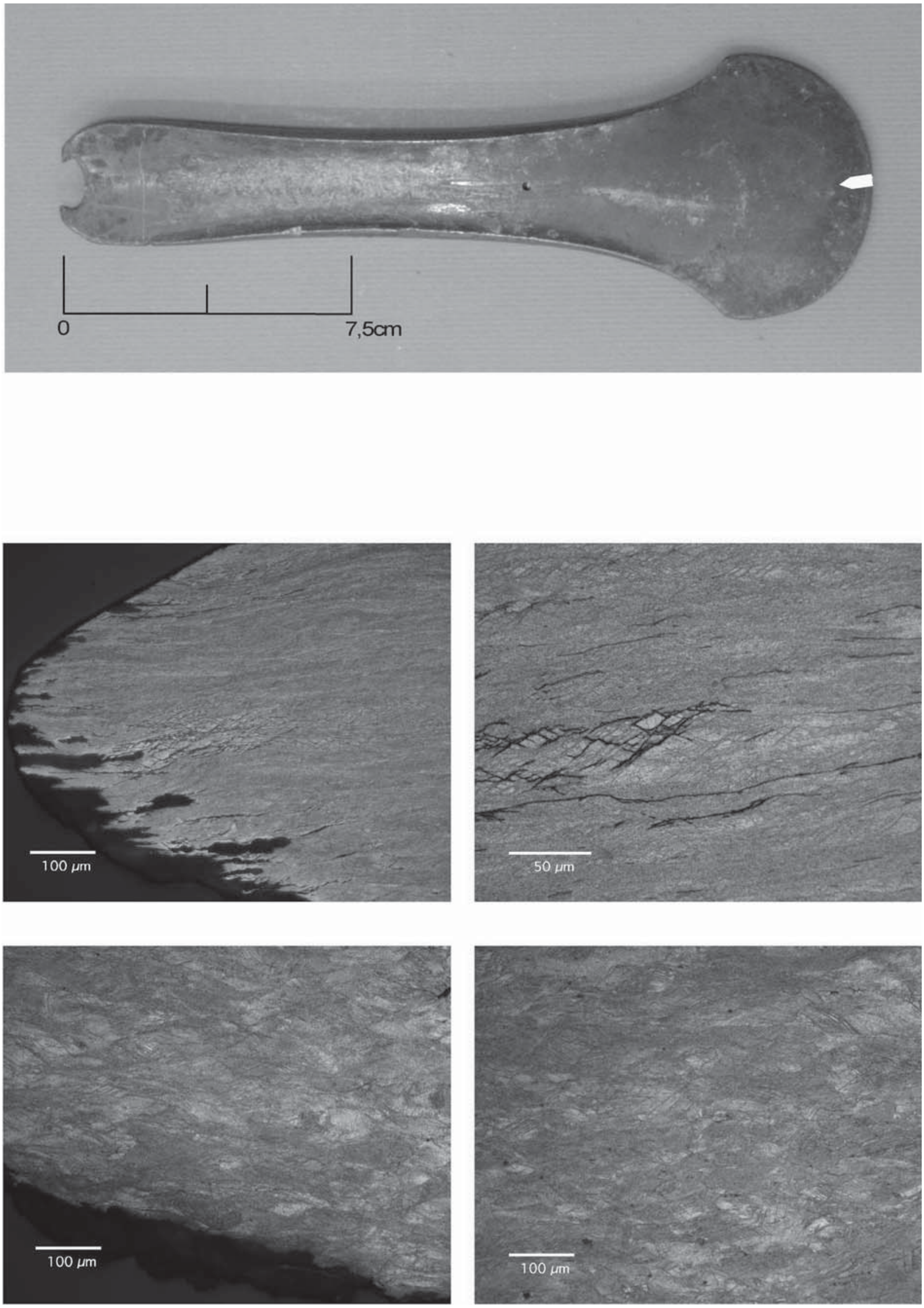


Tab. 113: Sample no. 168.

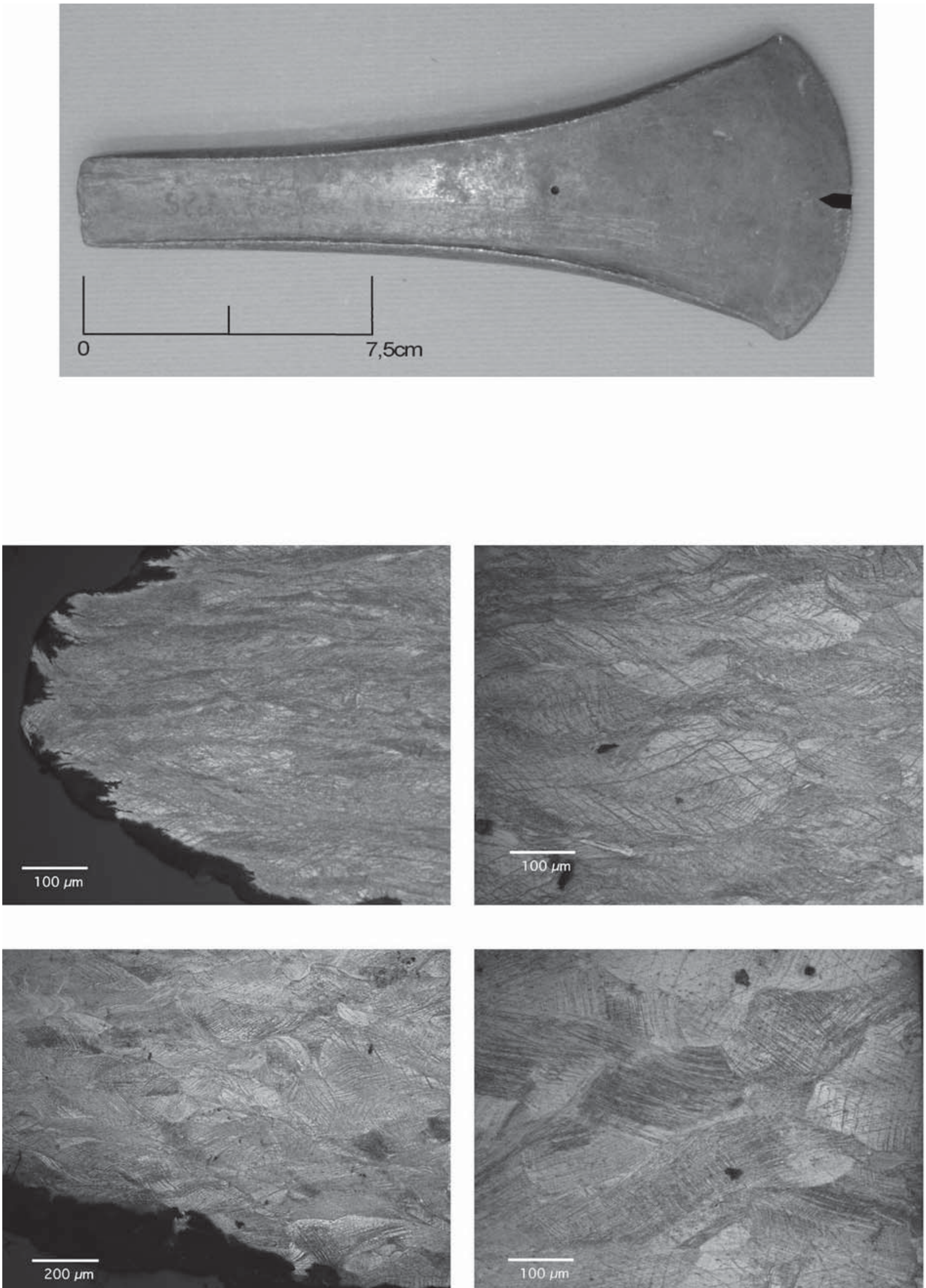




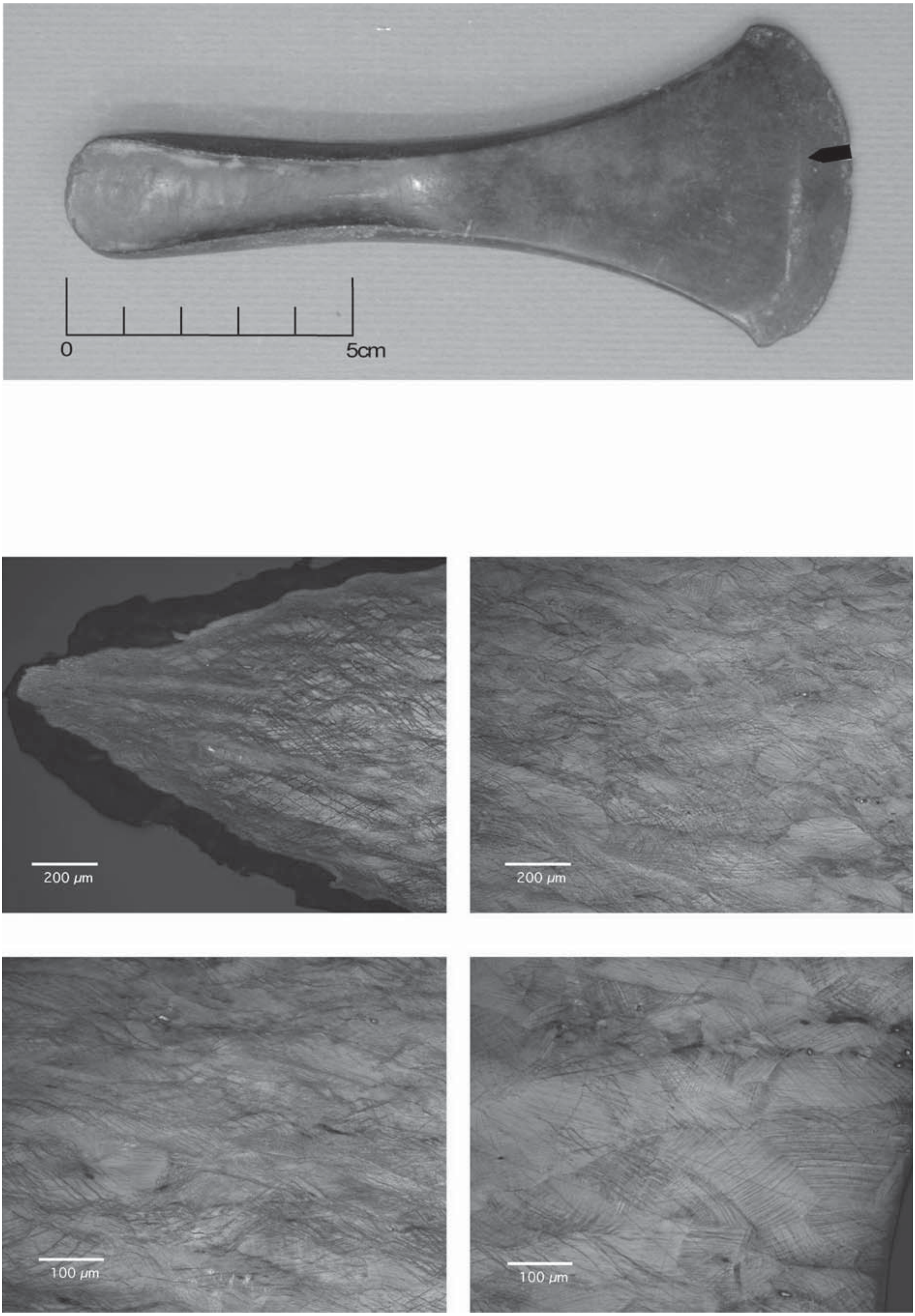
Tab. 114: Sample no. 169.



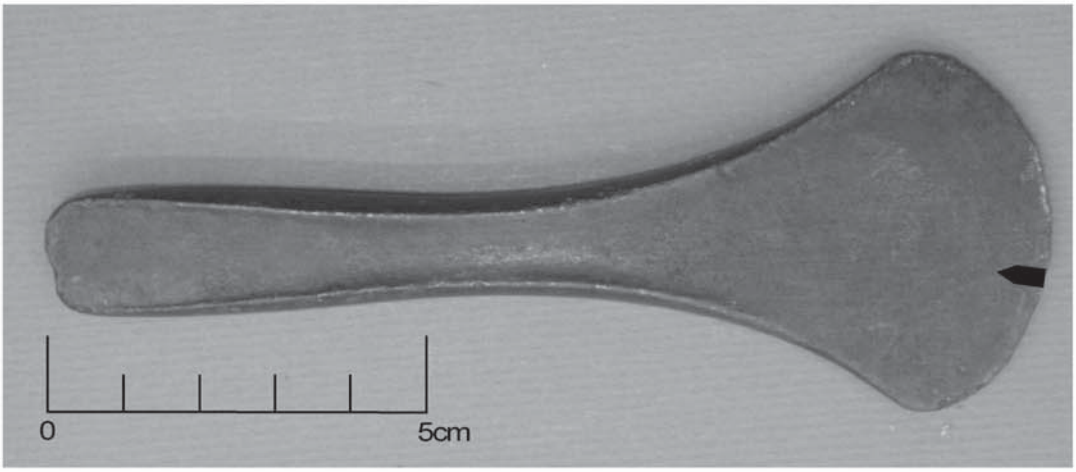
Tab. 115: Sample no. 171.

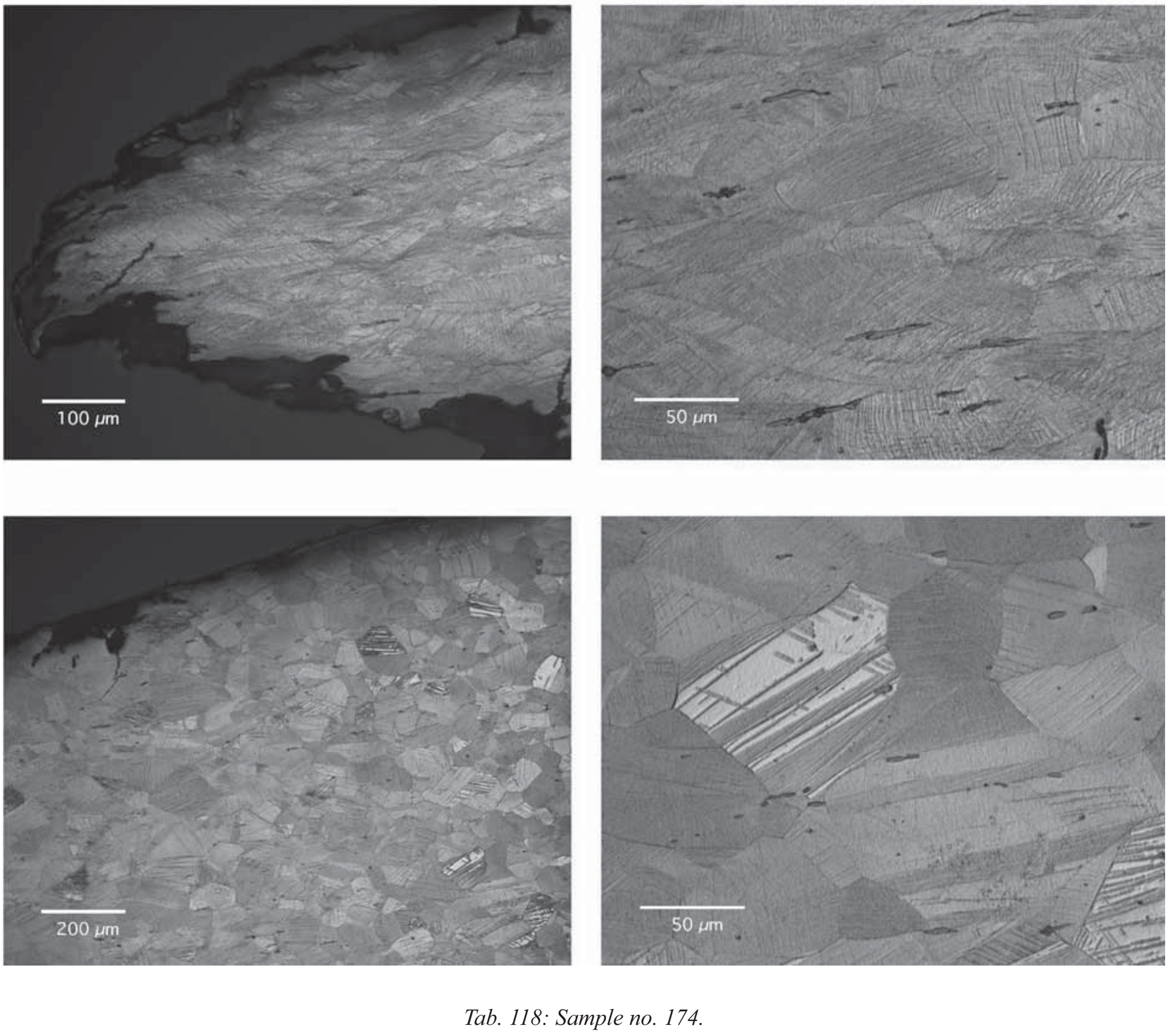


Tab. 116: Sample no. 172.



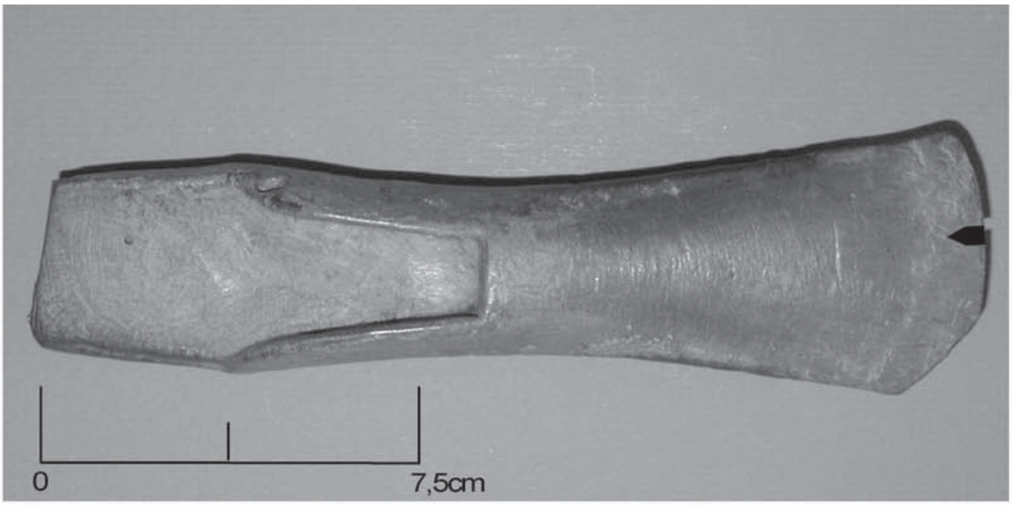
Tab. 117: Sample no. 173.

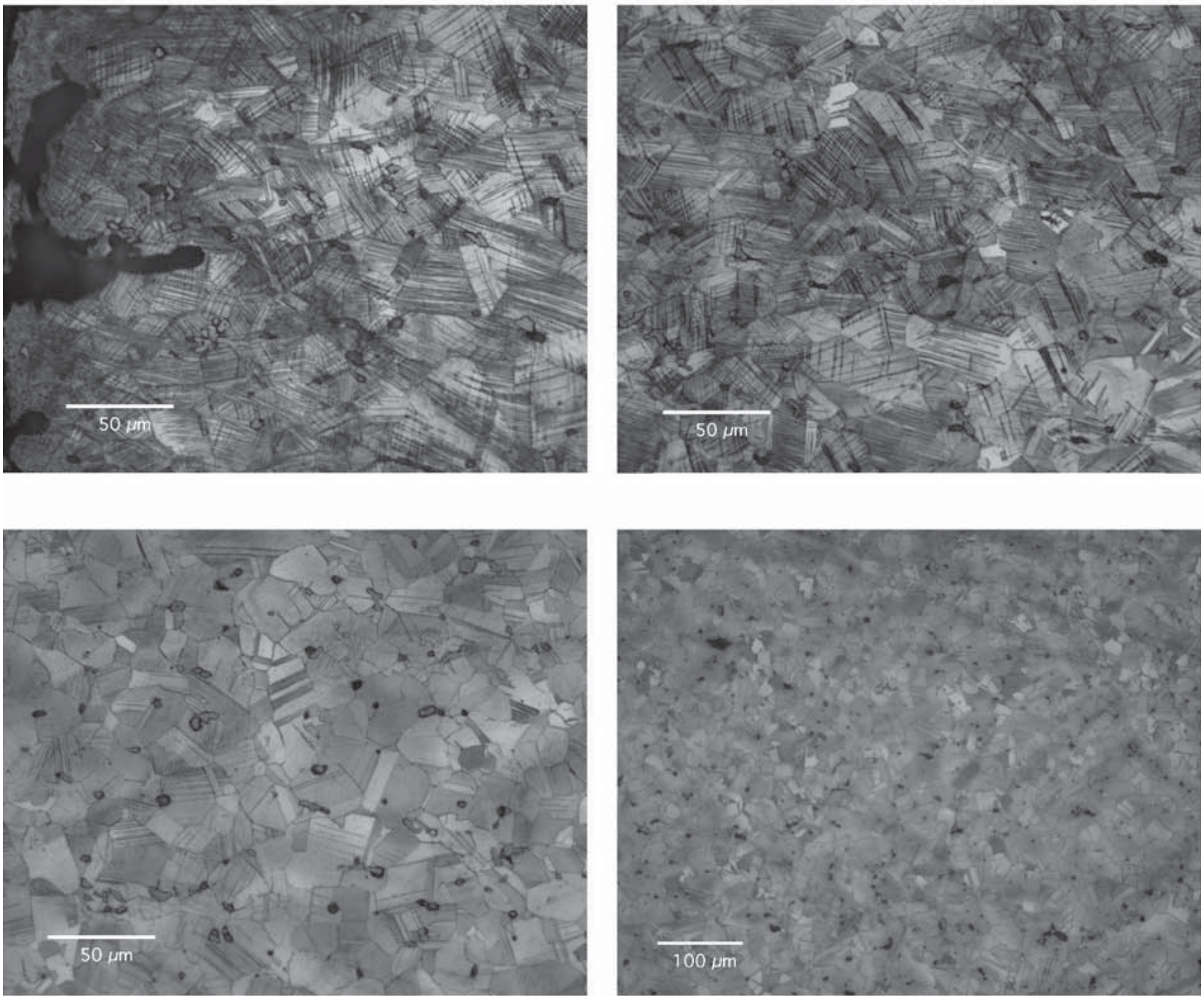




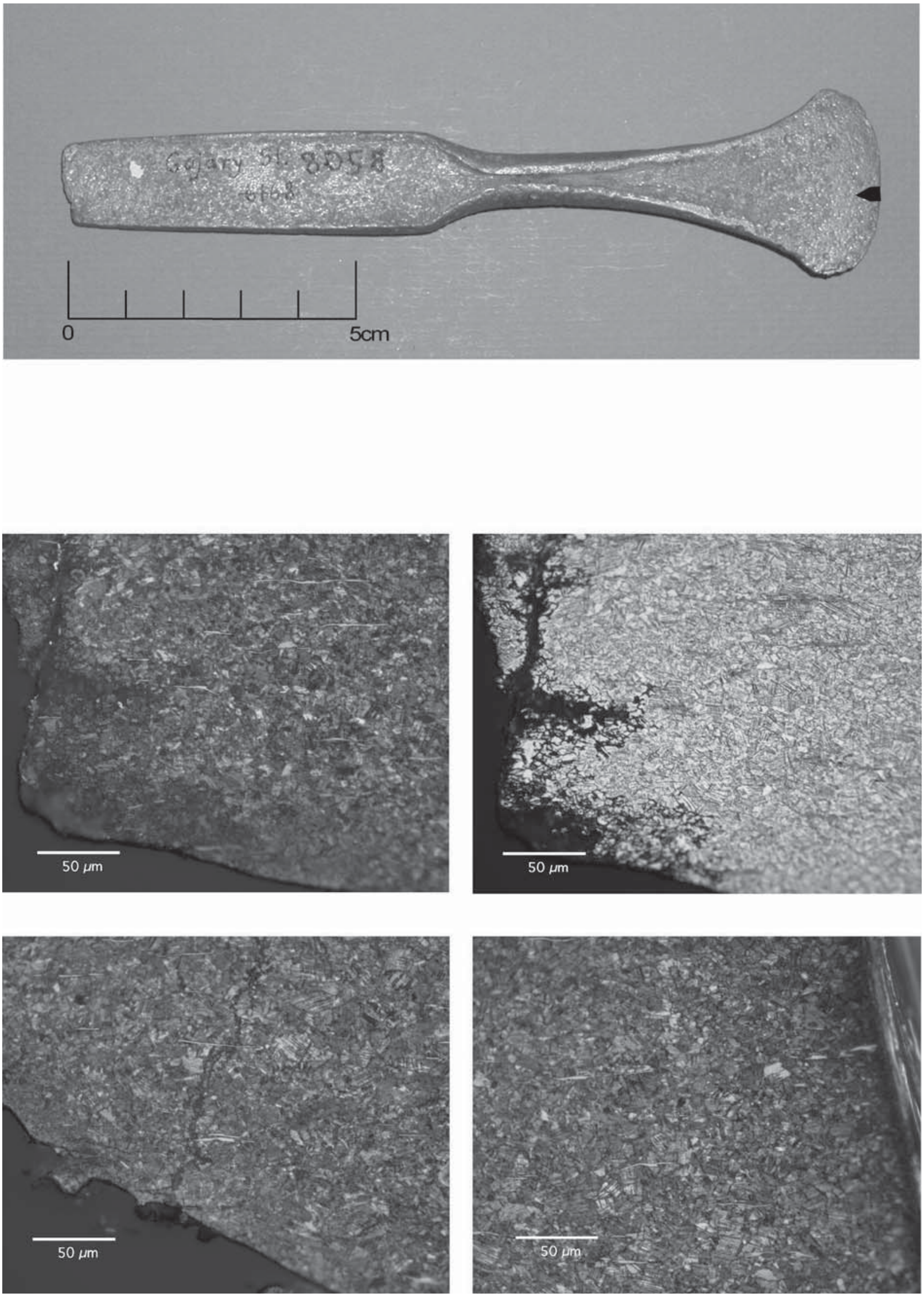
Tab. 118: Sample no. 174.

Bronze Age horizon 2 (late EBA to MBA/LBA palstaves etc.)		
Sample no.	***Origin / context***	***Museum / inv. no.***
50	Suché Brezovo SK stray find	Bratislava, Slov. Nár. Múz., 8435 Novotná 1970, 42 no. 250 (Absatzbeile mit gerader Rast)
53	Gajary SK stray find	Bratislava, Slov. Nár. Múz., 8058 Novotná 1970, 39 no. 215 (Absatzbeil mit spitzer Rast)
57	unknown unknown	Bratislava, Mest. Múz., 547 Novotná 1970, 36 no. 206 (Randleistenbeile mit flachem Nacken und bogenförmiger Schneide)
60	unknown unknown	Bratislava, Mest. Múz., 458 Novotná 1970, 36 no. 205 (Randleistenbeile mit flachem Nacken und bogenförmiger Schneide)
61	unknown unknown	Bratislava, Mest. Múz., 309 Novotná 1970, 39 no. 232 (Absatzbeile mit spitzer Rast)
63	unknown unknown	Bratislava, Mest. Múz., 617 Novotná 1970, 44 no. 262 (Absatzbeil-Sonderformen)
65	unknown unknown	Bratislava, Mest. Múz., 154 Novotná 1970, 39 no. 230 (Absatzbeile mit spitzer Rast)
66	unknown unknown	Bratislava, Mest. Múz., 582 Novotná 1970, 50 no. 324 (Oberständige Lappenbeile)
67	unknown unknown	Bratislava, Mest. Múz., 462 Novotná 1970, 46 no. 296 (Mittelständige Lappenbeile)
68	unknown unknown	Bratislava, Mest. Múz., 457 Novotná 1970, 39 no. 219 (Absatzbeile mit spitzer Rast)
70	unknown unknown	Bratislava, Mest. Múz., 121 Novotná 1970, 40 no. 243 (Absatzbeile mit spitzer Rast)
71	unknown unknown	Bratislava, Mest. Múz., 130 Novotná 1970, 44 no. 263 (Absatzbeil-Sonderformen)
73	unknown unknown	Bratislava, Mest. Múz., 661 Novotná 1970, 39 no. 220 (Absatzbeile mit spitzer Rast)
115	Jelšovce SK grave	Nitra, AÚSAV, grave 119 Bátora 2000, 75, tab. 11.30
116	Jelšovce SK grave	Nitra, AÚSAV, grave 613 Bátora 2000, 292, tab. 52.12
117	Jelšovce SK grave	Nitra, AÚSAV, grave 602 Bátora 2000, 286, tab. 51.3
150	Dambořice CZ hoard(?)	Brno, 69390 Říhovský 1992, 101 no. 225 (Gr. IX, Typ 6a, Var. Cd)

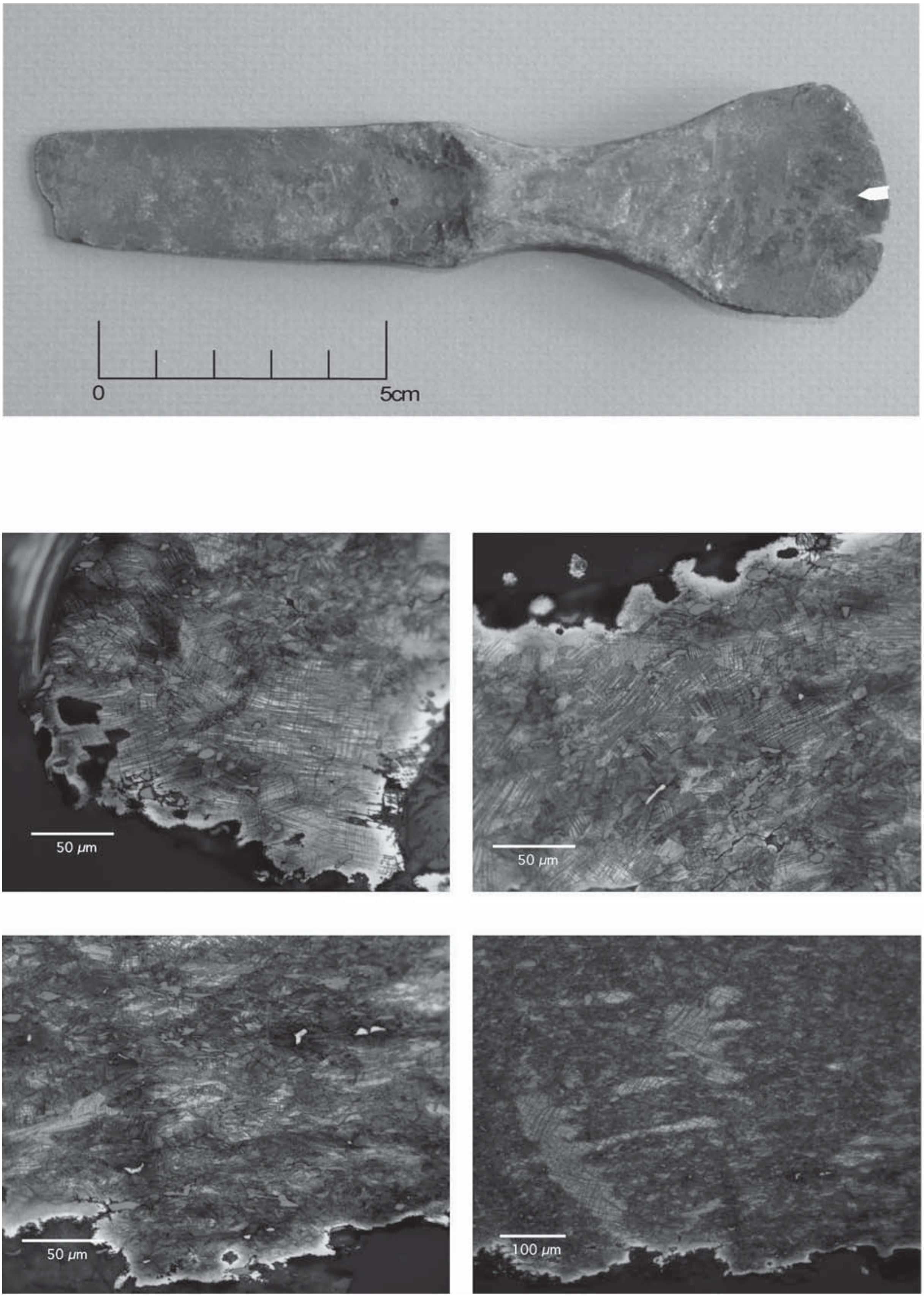




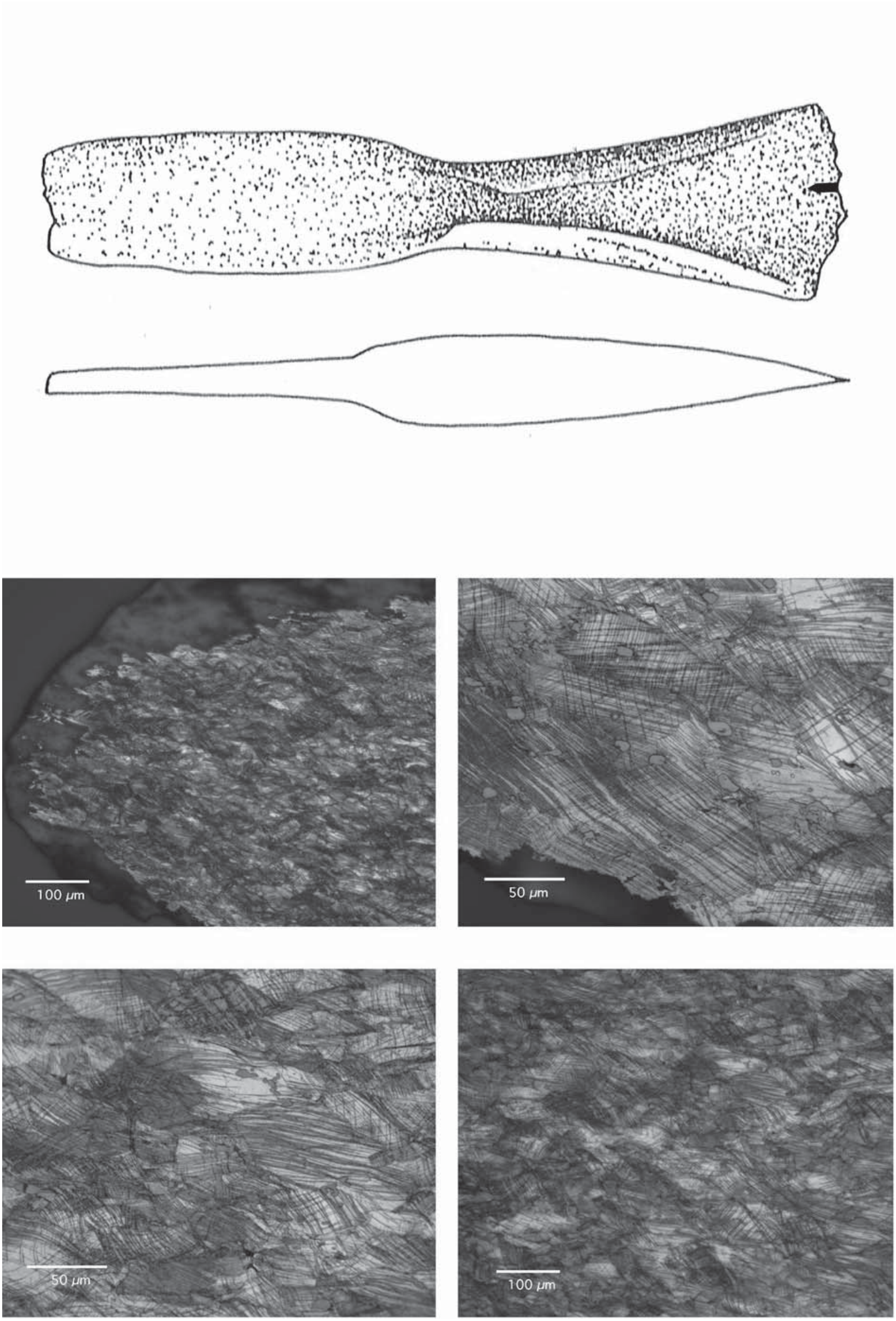
Tab. 119: Sample no. 50.



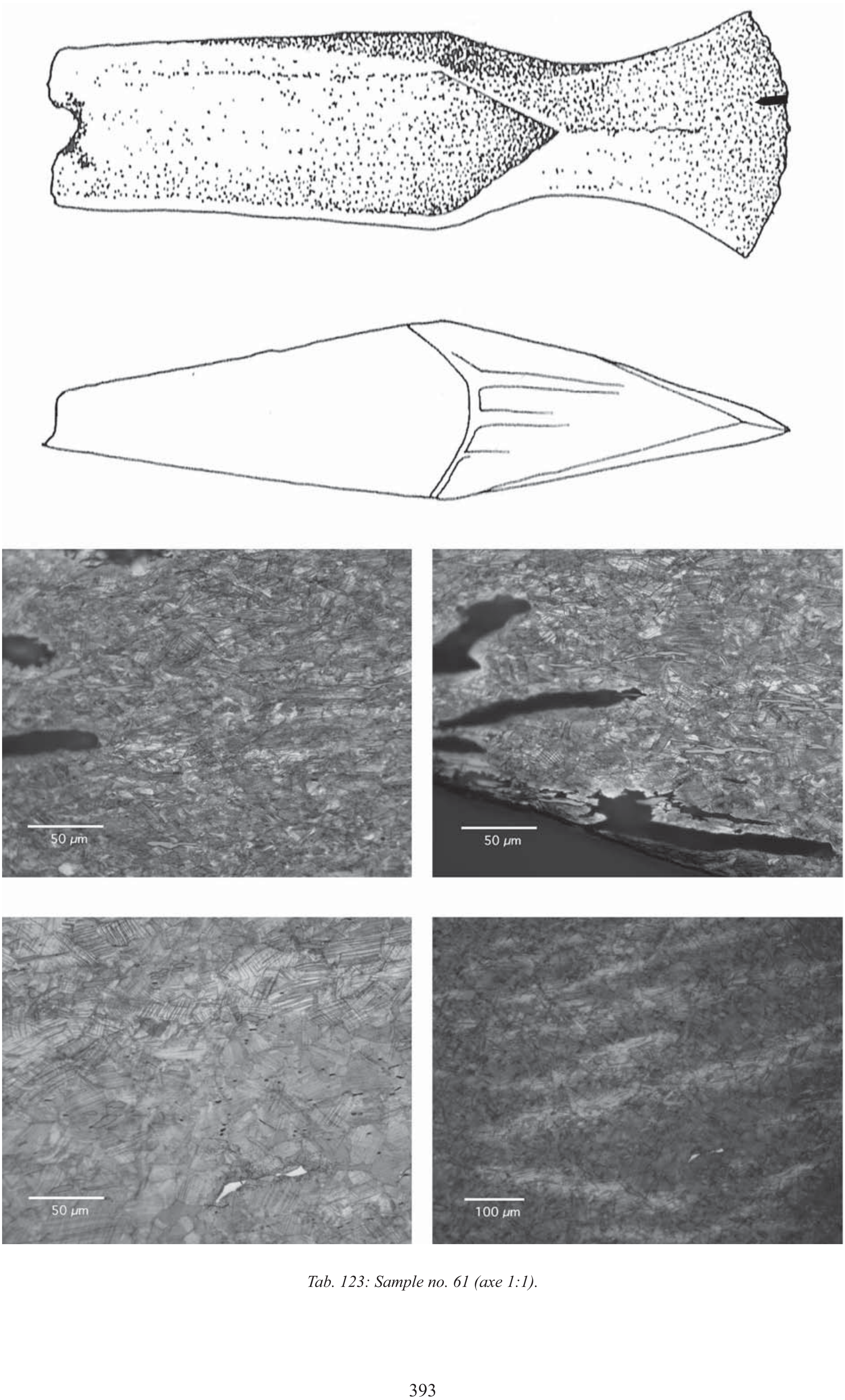
Tab. 120: Sample no. 53.



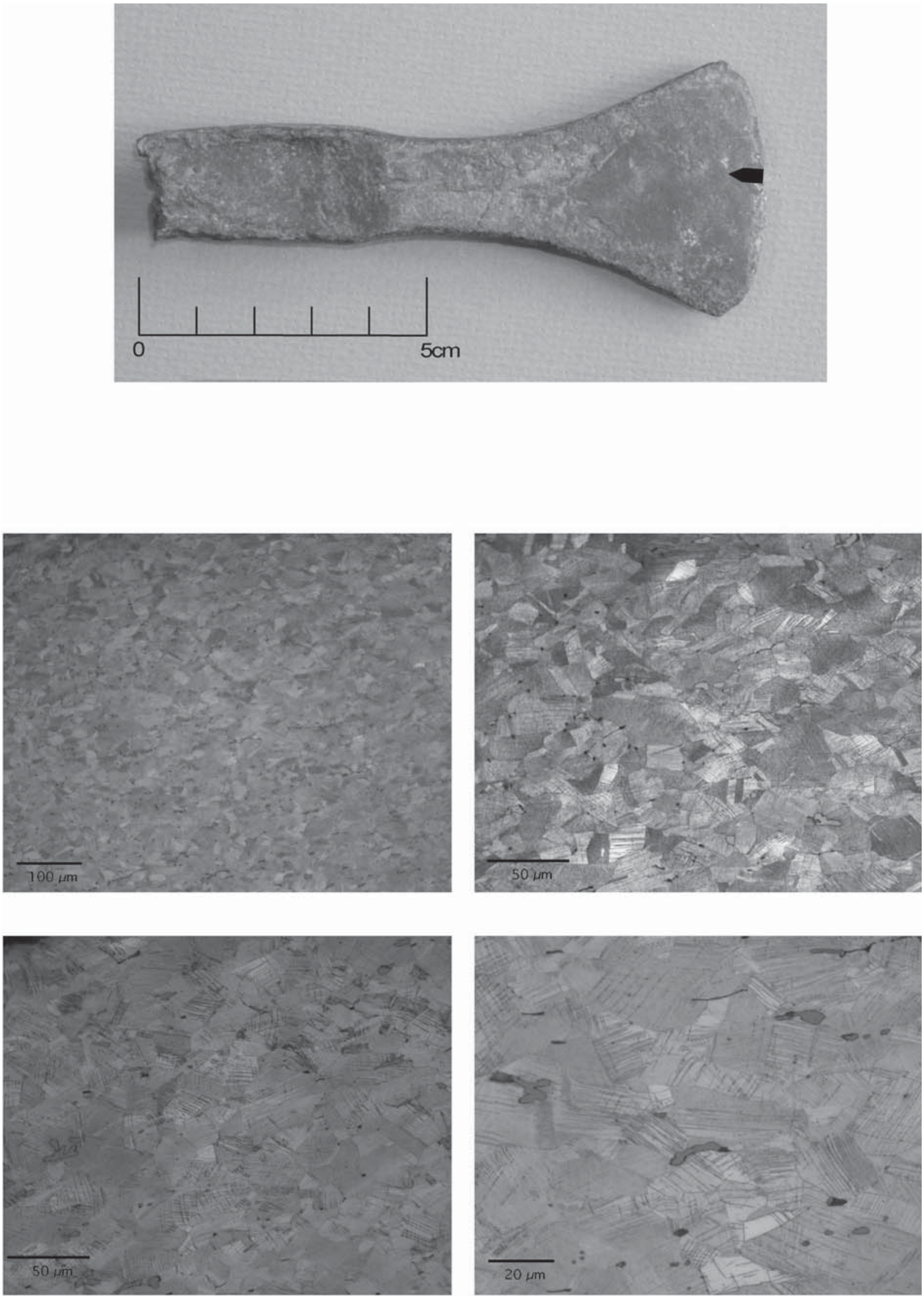
Tab. 121: Sample no. 57.



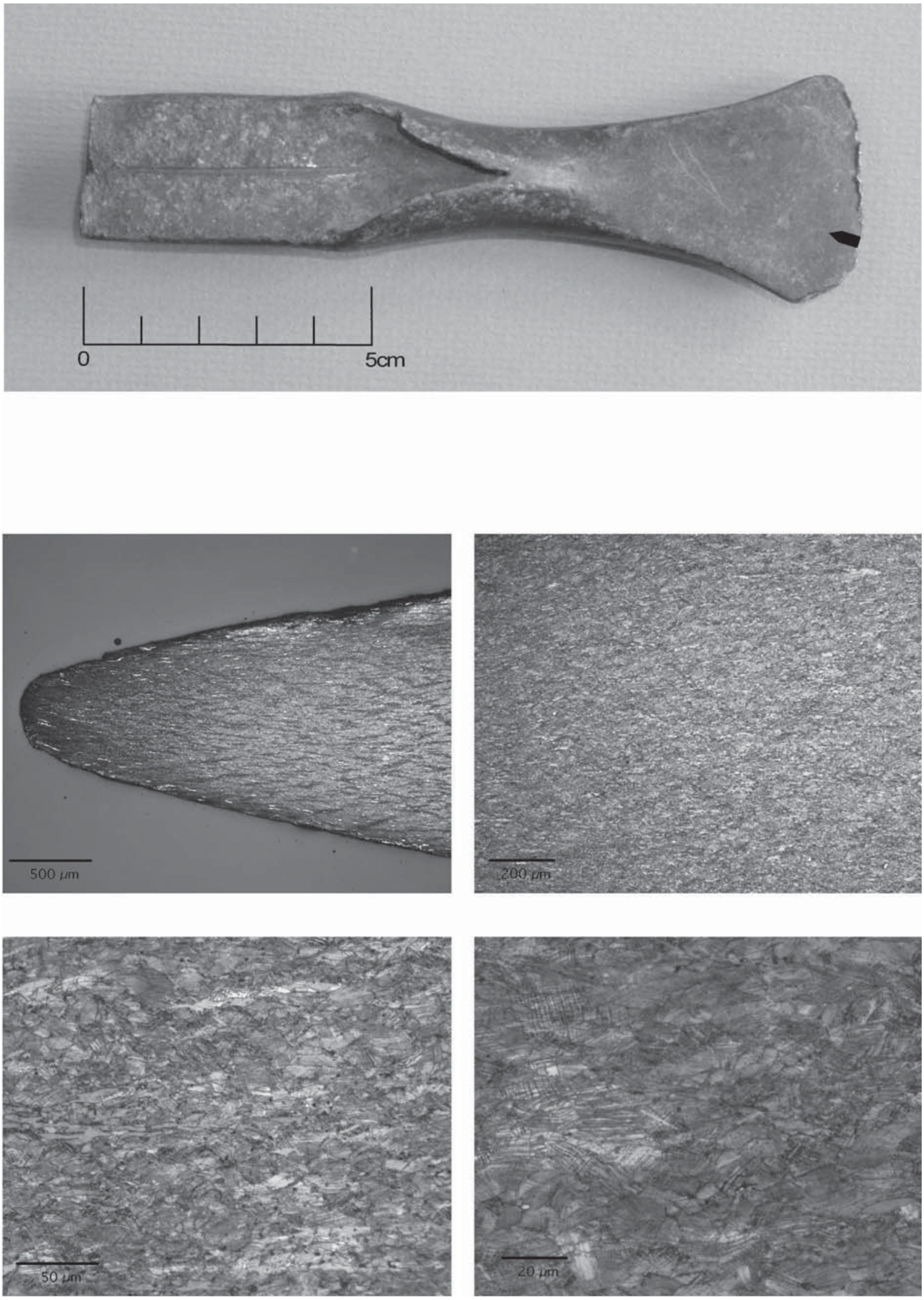
Tab. 122: Sample no. 60 (axe 1:1).



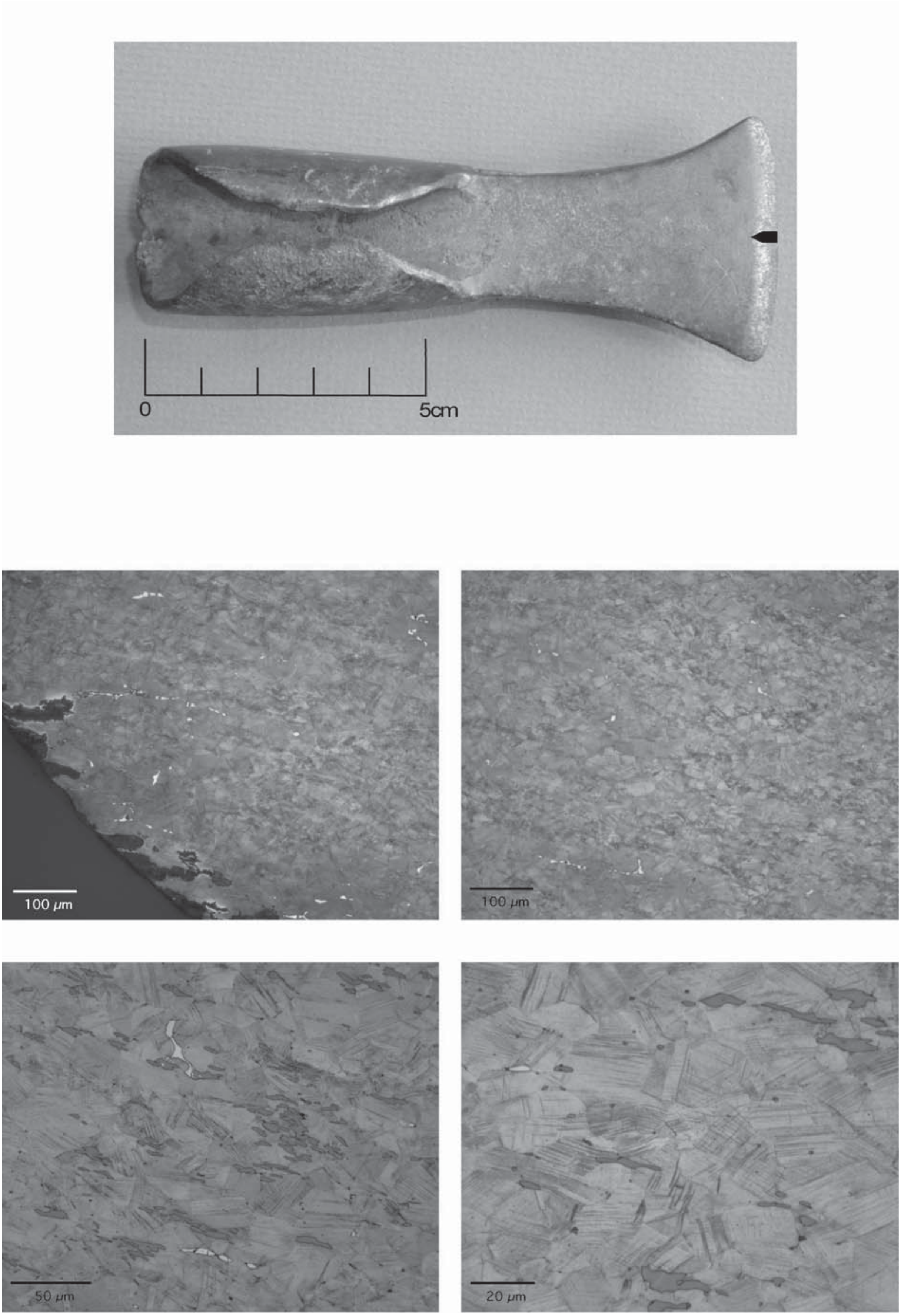
Tab. 123: Sample no. 61 (axe 1:1).



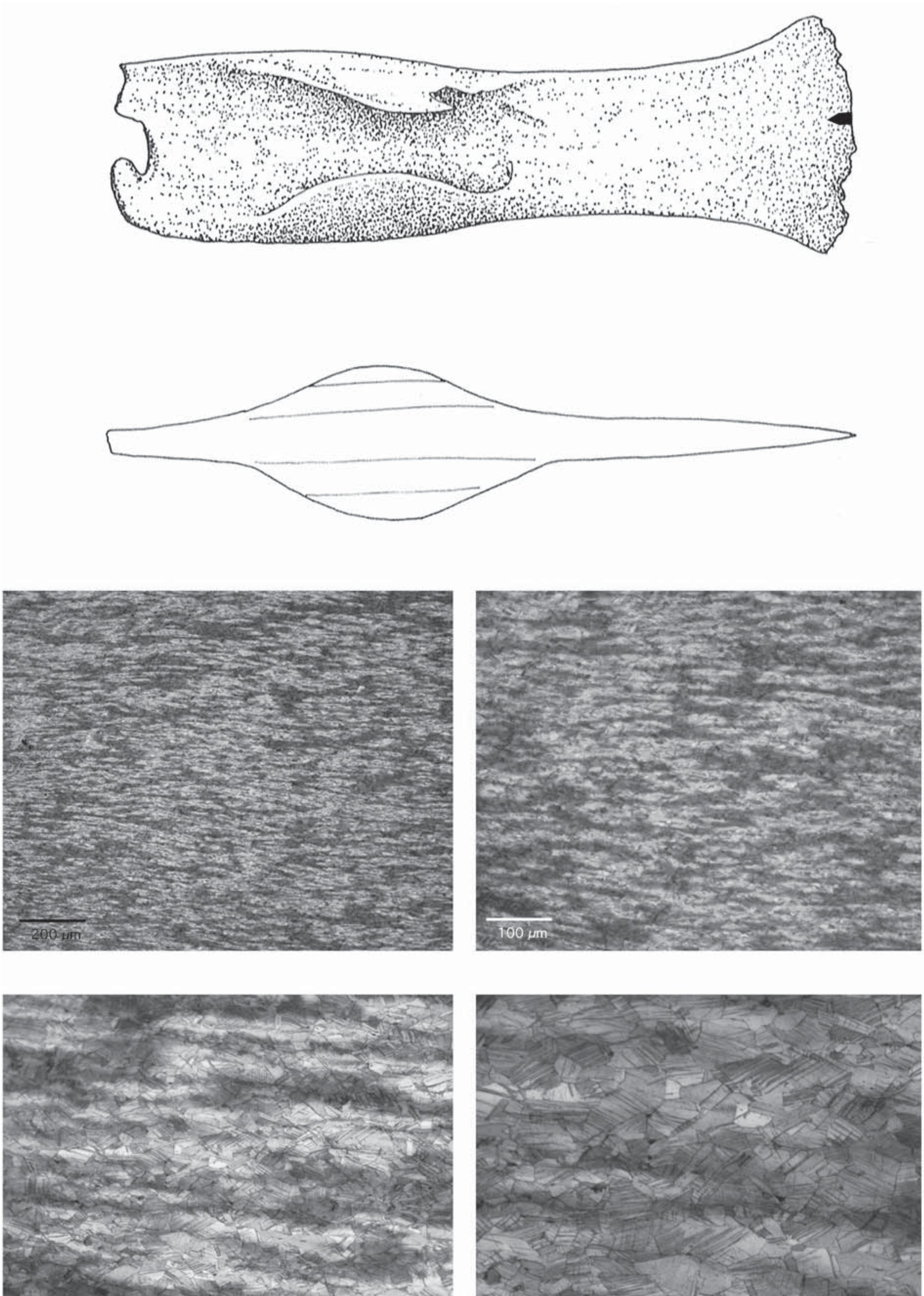
Tab. 124: Sample no. 63.



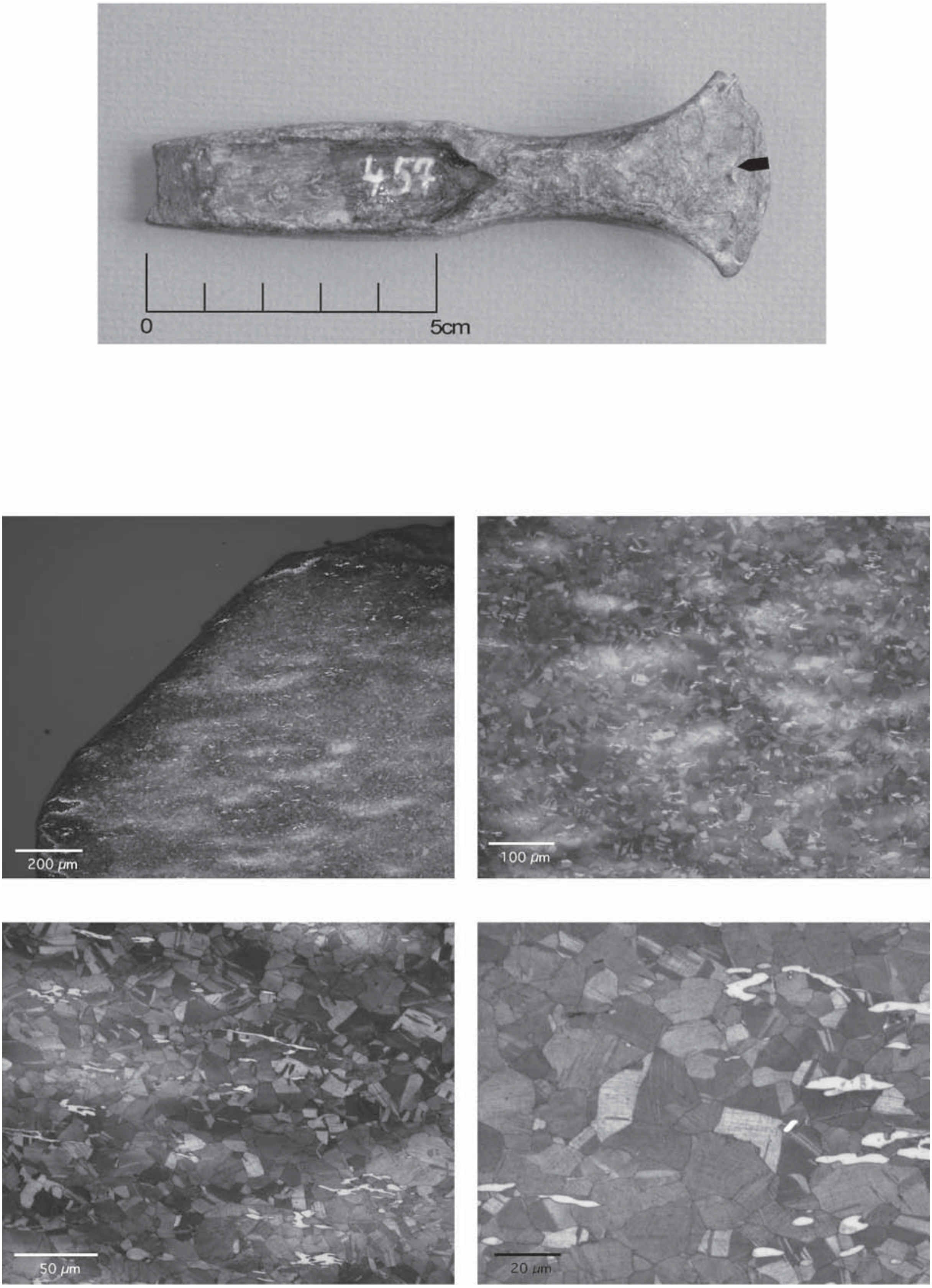
Tab. 125: Sample no. 65.



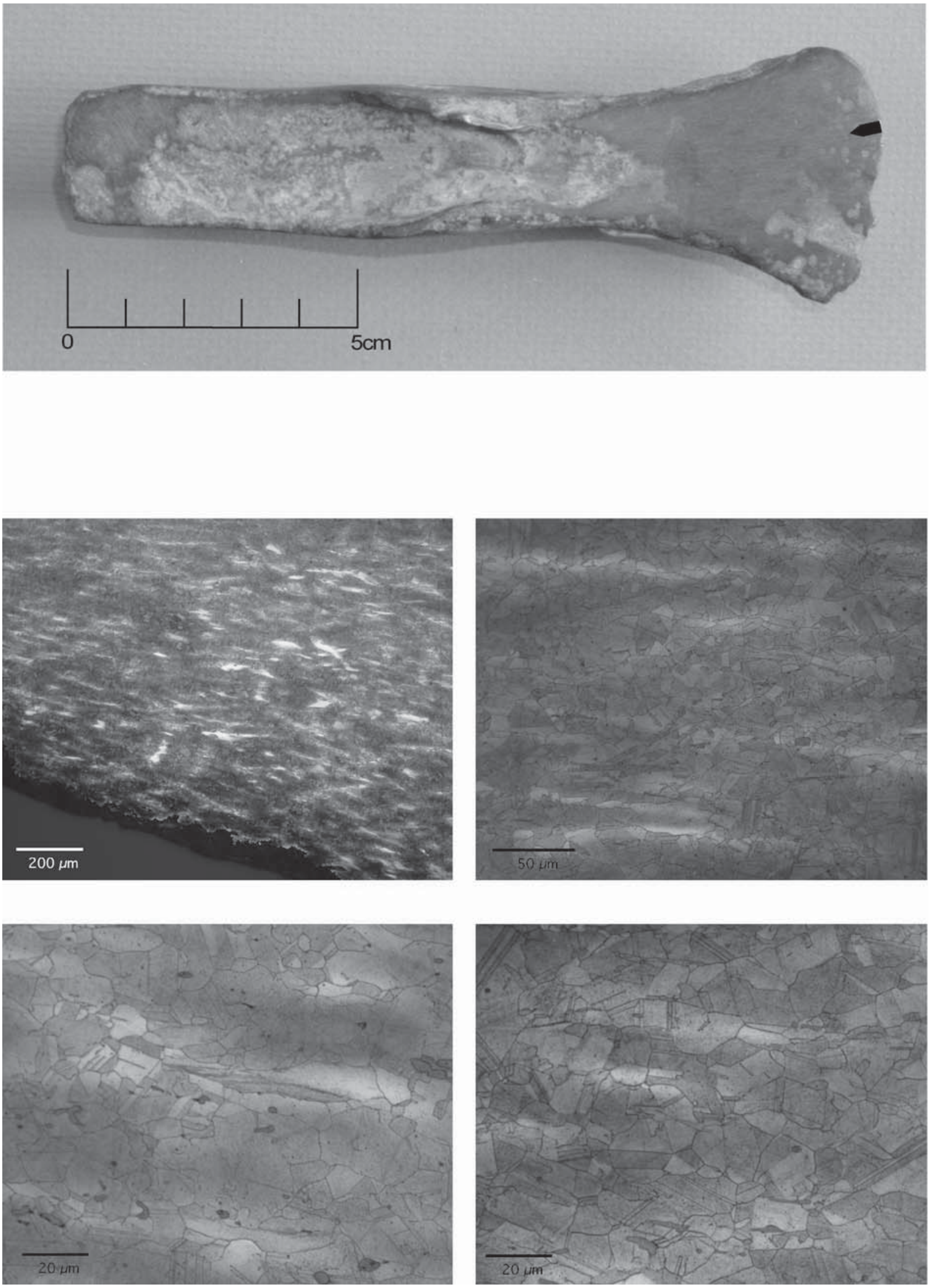
Tab. 126: Sample no. 66.



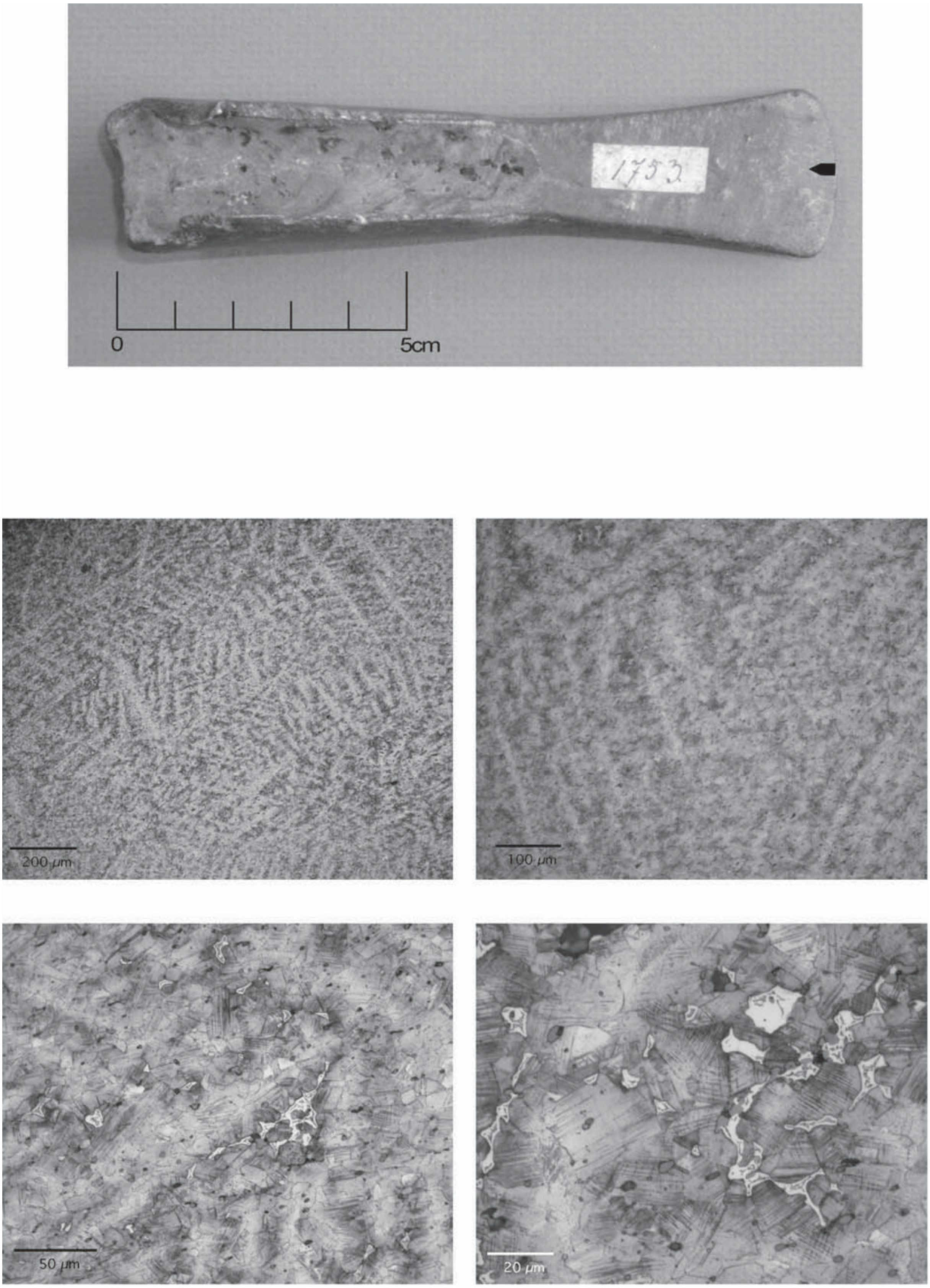
Tab. 127: Sample no. 67 (axe 3:4).



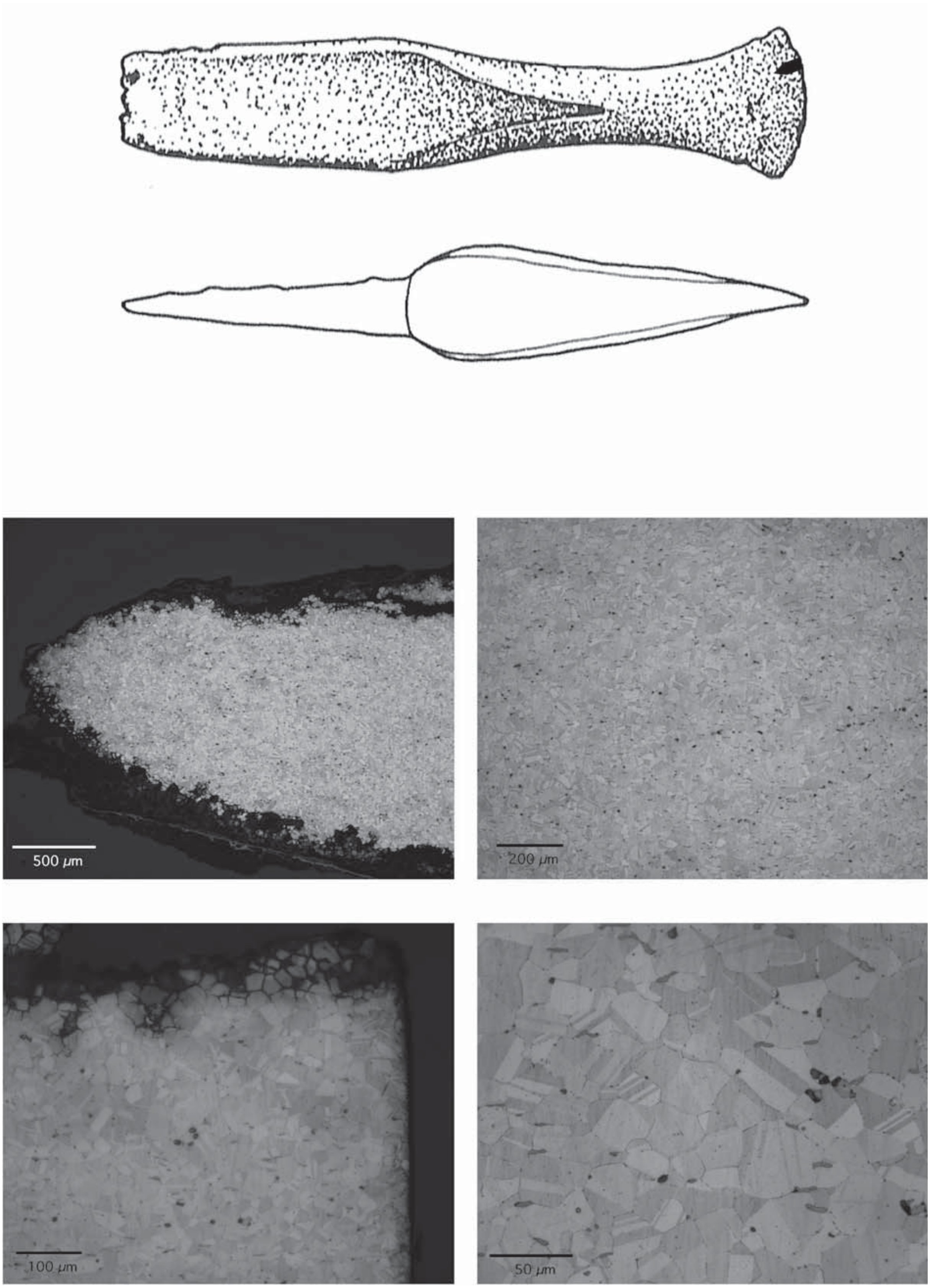
Tab. 128: Sample no. 68.



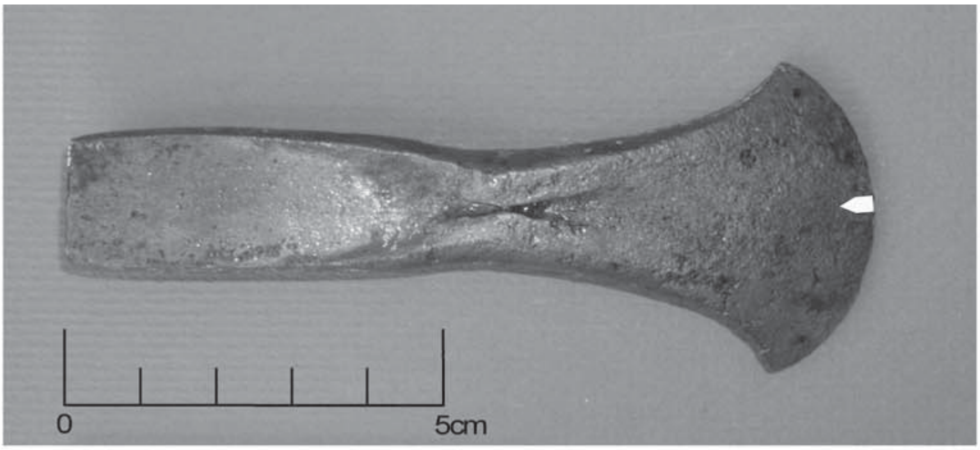
Tab. 129: Sample no. 70.

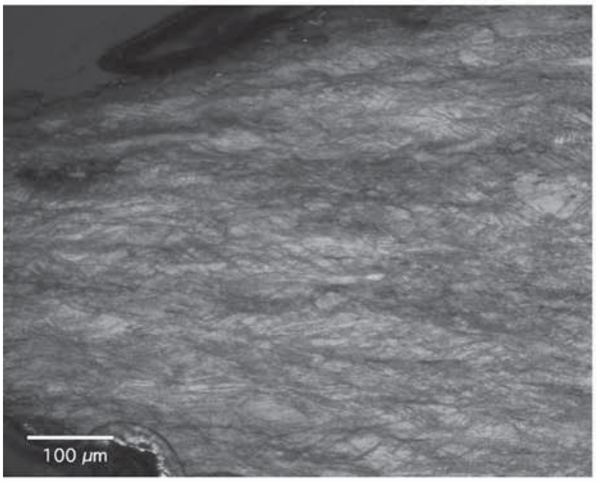


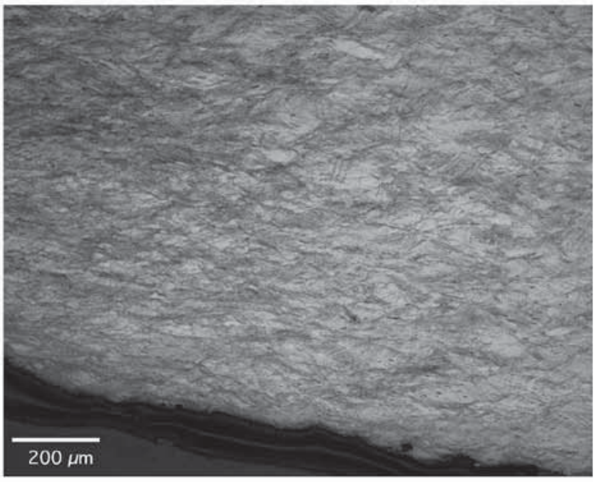
Tab. 130: Sample no. 71.

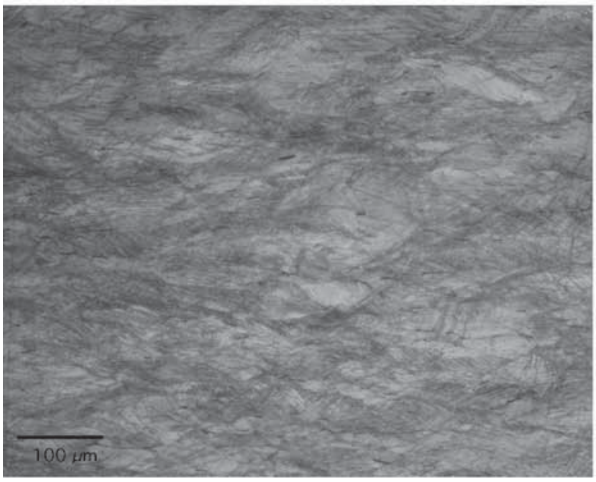


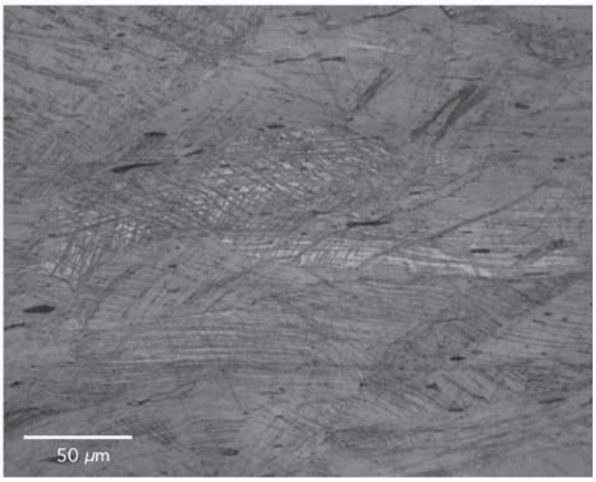
Tab. 131: Sample no. 73 (axe 1:1).



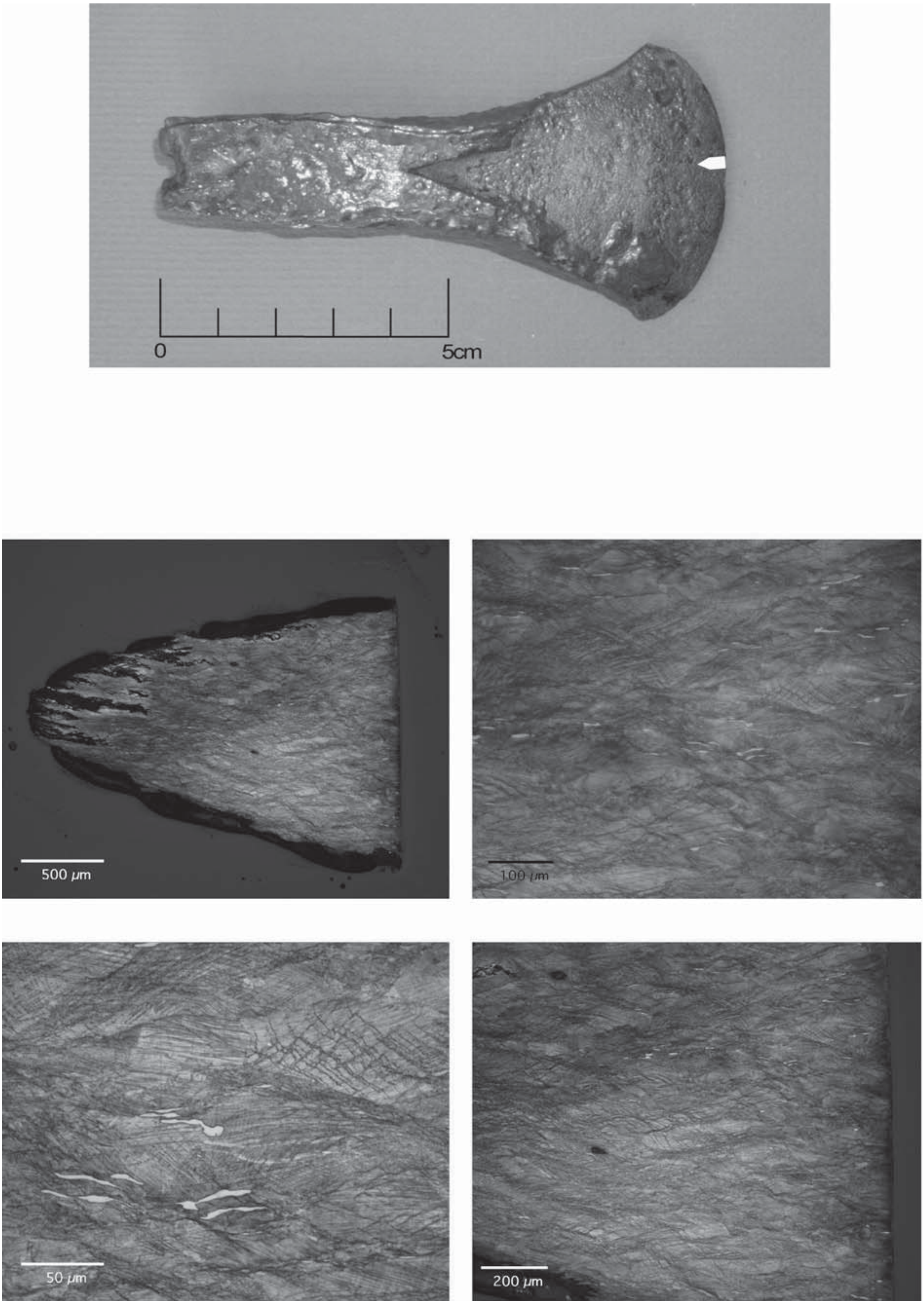




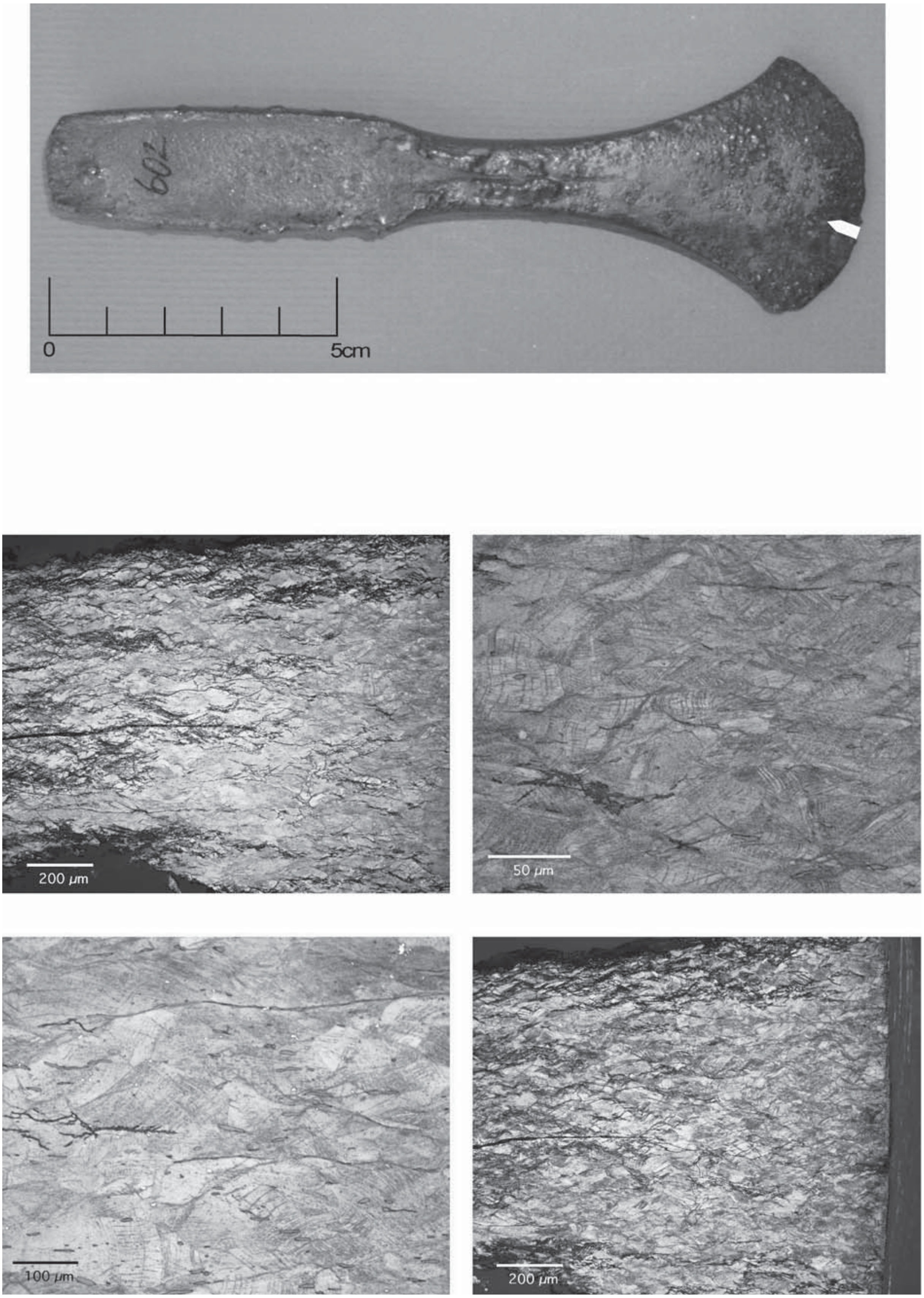




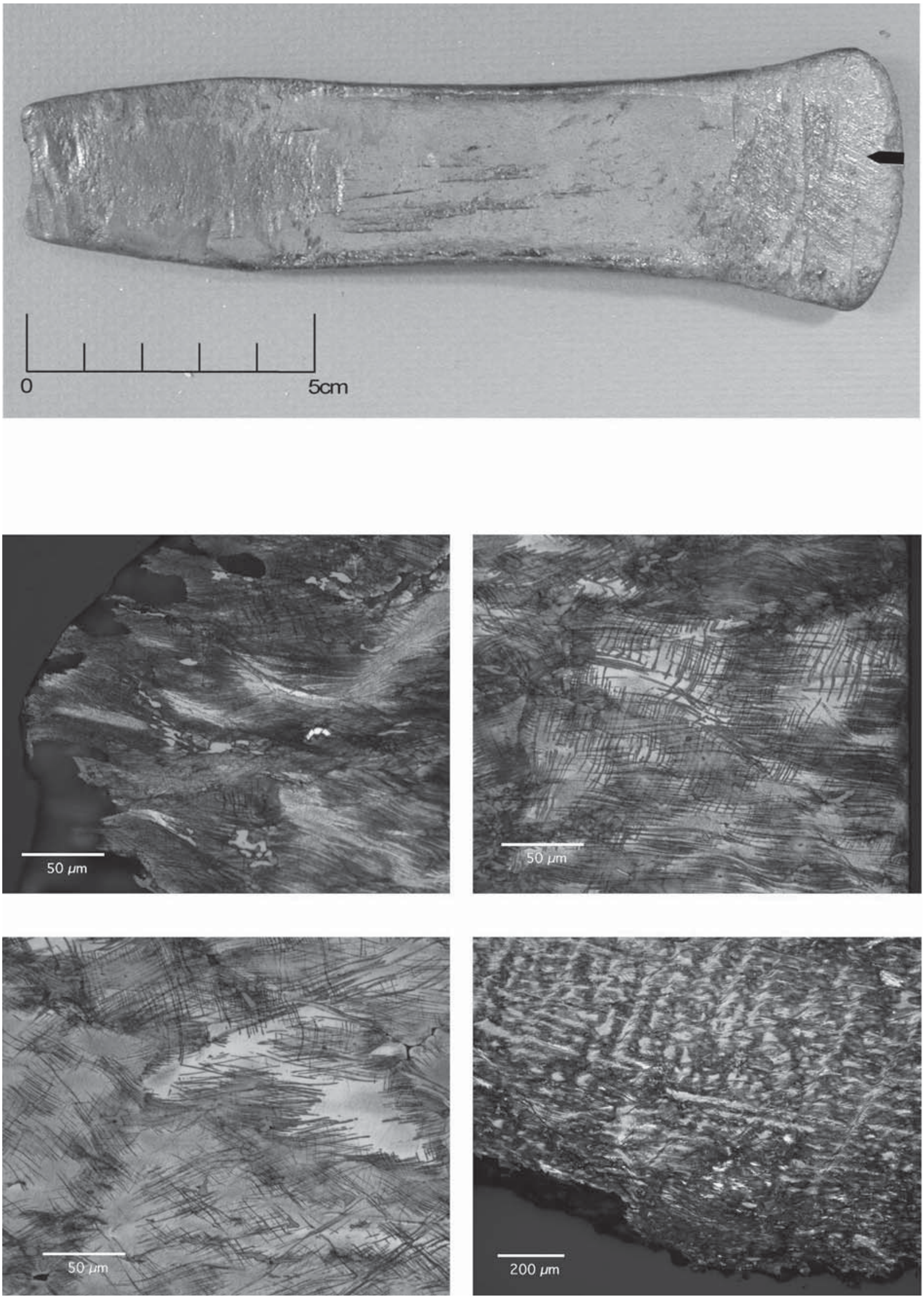
Tab. 132: Sample no. 115.



Tab. 133: Sample no. 116.



Tab. 134: Sample no. 117.



Tab. 135: Sample no. 150.